FIFTY YEARS OF ELECTRICITY

THE MEMORIES OF AN ELECTRICAL ENGINEER

BY

J. A. FLEMING, M.A., D.Sc., F.R.S.

UNIVERSITY PROFESSOR OF ELECTRICAL ENGINEERING IN THE UNIVERSITY OF LONDON; HUGHES GOLD MEDALLIST OF THE ROYAL SOCIETY OF LONDON; MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS; FELLOW OF UNIVERSITY COLLEGE, LONDON; SOMETIME FELLOW OF ST. JOHN'S COLLEGE, CAMBRIDGE; MEMBER OF THE ROYAL INSTITUTION OF GREAT BRITAIN; AUTHOR OF "THE PRINCIPLES OF ELECTRIC WAVE TELEGRAPHY," "THE ALTERNATE CURRENT TRANSFORMER," "THE THERMIONIC VALVE AND ITS APPLICATIONS IN WIRELESS TELEGRAPHY AND TELEPHONY," "THE PROPAGATION OF ELECTRIC CURRENTS IN TELEPHONE AND TELEGRAPH CONDUCTORS," ETC., ETC.

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FOREWORD

This book makes no claim whatever to be a systematic treatise on electricity or electrical engineering, but is simply intended as an attempt to place before the intelligent general reader a fairly comprehensive view of the chief triumphs of applied electricity during the last half-century. It may perhaps assist junior engineering students in obtaining a preliminary acquaintance with the outlines of a subject they will study in greater detail in other books.

The physical agencies, Electricity and Magnetism, have become so much the servants of mankind that no educated person should be entirely ignorant of the manner in which they render their services. They have come to our assistance chiefly in solving the problems connected with the increase of the population of the world and its concentration in large cities, but in future they may be exerted in an opposite direction, and, by annihilating space and time, prevent or render unnecessary this concentration, which has so many serious evils attaching to it.

The great engineering problem of the future is the production and distribution of power.

The possible exhaustion of the supply of coal, or, what comes to the same thing, the increased and ever-increasing costliness of obtaining it in Europe, more and more turns the thoughts of scientists to the possibility of liberating the enormous stores of latent energy in the atoms of matter.

The engine of the future may be an explosion engine operated by energy released suddenly by some disruption of atoms, and not one worked by the pressure of steam or combustion of oil vapour.

There are also vast possibilities connected with improvements in the efficiency of sources of illumination, and in the wireless transmission of energy, which may materialise at any time and make ancient history of our present achievements.

The next fifty years of electricity are a subject for attractive medita-

tions, but the records of the past half-century are worthy of attention as showing how and where we stand.

In conclusion, the Author desires to record his thanks and obligations to those firms and gentlemen who have kindly furnished photographs of apparatus or permitted illustrations to be borrowed from their published papers or books. This courtesy has as far as possible been acknowledged under the diagrams. They include: Igranic Electric Co., Ltd., The Weston Electrical Instrument Co., Ltd., The India Rubber, Gutta Percha and Telegraph Works Co., Ltd., Automatic Telephone Manufacturing Co., Ltd., Creed & Co., Ltd., Mr. H. Tinsley, Mr. Donald Murray, Muirhead & Co., Ltd., Siemens Bros. & Co., Ltd., Mr. J. E. Kingsbury and Messrs. Longmans, Green & Co., Ltd., Western Electric Co., Ltd., Lieut.-Colonel O'Meara and the Institution of Electrical Engineers, The British Thomson-Houston Co., Ltd., General Electric Co. (America), The General Electric Co., Ltd., Ferranti Ltd., The British Electric Transformer Co., Ltd., Bruce, Peebles & Co., Ltd., Simplex Conduits, Ltd., The English Electric and Siemens Supplies, Ltd., The Edison and Swan Electric Co., Ltd., The British Insulated and Helsby Cable Co., Ltd., Hurst, Nelson & Co., Ltd., Chamberlain & Hookham, Ltd., Metropolitan-Vickers Electrical Co., Ltd., The English Electric Co., Ltd., Marryat & Place, Ltd., Berry's Electric, Ltd., The Chloride Electric Storage Co., Ltd., The Underground Electric Railway Co., Ltd., The British Aluminium Co., Ltd., the Cambridge and Paul Instrument Co., Ltd., Johnson & Phillips, Ltd., The Lancashire Dynamo and Motor Co., Ltd., The Gaumont Co., The General Post Office, The Institution of Electrical Engineers of London, The American Institute of Electrical Engineers and Mr. H. M. Hobart, The Radio Corporation of America, The Royal Institution of Great Britain, and the Proprietors of *Conquest*, *The Wireless World*, *The Radio Review*, and Marconi's Wireless Telegraph Co., Ltd.

J. A. F.

University College, London.
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THE MEMORIES OF AN ELECTRICAL ENGINEER

INTRODUCTION

ELECTRICAL ENGINEERING BEFORE 1870

THE fifty years between 1870 and 1920 have been years of immense progress in scientific knowledge and its practical applications. In hardly any branch of technics have these advances been more remarkable than in connection with the sciences of Electricity and Magnetism. Few persons realise the degree to which we have become dependent on these physical agencies as the willing servants of mankind in our complex modern civilisation.

Our age is essentially an age of iron and steel. One of the unique properties of the metal iron is that it can be magnetised. This power is exhibited, but to a much less degree, by two other metals, viz., nickel and cobalt. Take an iron bar, say a poker, and wind round it spiral coils of copper wire, this wire being spun over with silk or cotton to insulate the turns. Connect the ends of this wire to a battery or source of electric current and the iron instantly becomes a powerful magnet. It will attract and hold up other pieces of iron and exhibits many remarkable properties as long as the electric current flows round it. Such an arrangement is called an *electromagnet*, and it was first given to us by an English electrician, William Sturgeon (see Plate 1), in 1825, who employed, however, a winding consisting of only a single layer of rather thick copper wire (see Fig. 1). Joseph Henry (1797—1878), in the United States, bestowed on the electromagnet additional powers by winding it with very many turns of fine silk-covered copper wire (see Fig. 2). J. P. Joule, a British engineer, invented divers forms of improved

electromagnet about 1840 remarkable for their great power of lifting other masses of iron. Large electromagnets made on Joule's principles are now in common use in engineering works, and are used for lifting heavy masses of iron and materials such as scrap iron, which would be very difficult to handle without this aid (see Plates 2 and 3). The electromagnet, in some form or another, is the basis of all modern electric telegraphy, of telephony, of machines for generating electric currents by

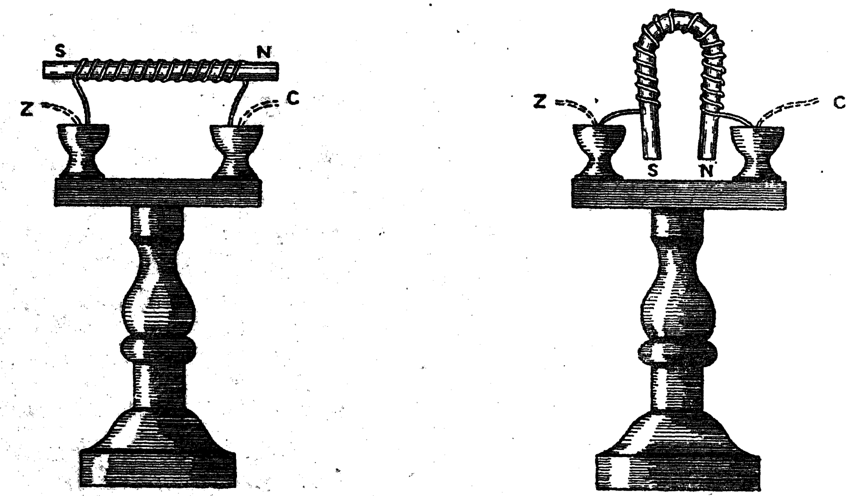

FIG. 1.—Sturgeon's first Electromagnets: Bar and Horse-shoe. The objects like egg-cups are cups full of mercury by which a connection was made between the magnet wire winding and the battery which supplied the electric current to excite it.

mechanical power called dynamos, of electric motors, electric bells, induction coils, and countless other appliances used in everyday life.

The work of the electrical engineer for the last fifty years has been largely concerned with the development and utilisation of the electromagnet, and this again has been based upon the scientific study of this peculiar property of iron by numerous investigators. The best method of testing the value of a possession to us is to imagine our condition if we lost it.

Let us then suppose that by some freak of nature this much used metal iron suddenly lost its capability of being magnetised without sustaining

PLATE 1.

WILLIAM STURGEON. (1783—1850.)

The inventor of the electromagnet. He was also the first to construct an electric motor, and was an early pioneer in electrotechnics, making many important inventions and discoveries. His electromagnet was described in the *Transactions of the Royal Society of Arts*, in vol. 43, p. 38, 1825. (See page 1.)

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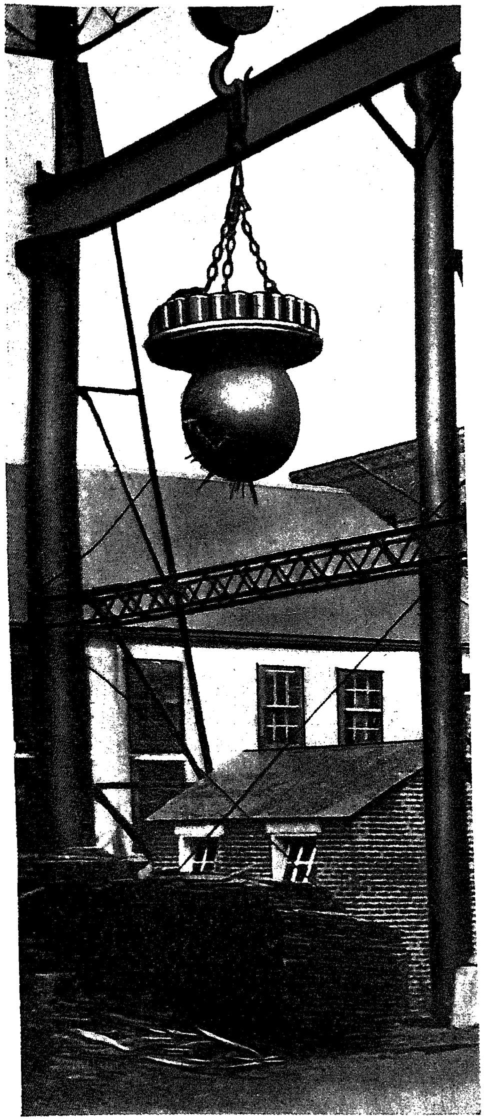
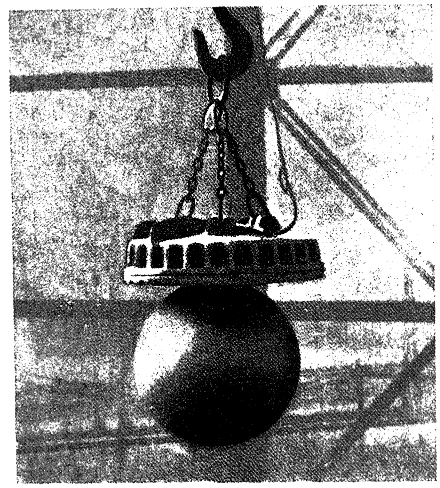
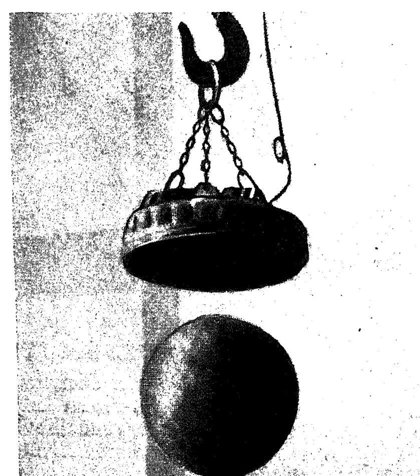
PLATE 2.





An Iron Ball weighing 20,000 lbs. upheld by the attraction of a 62-inch Igranic Electromagnet.



[*By permission of the Igranic Electric Company, Ltd.*

An Igranic Electromagnet lifting a large Iron Ball, called a Skull-cracker. When the current is cut off from the magnet, the ball drops, and the blow is utilised for breaking up old machinery or iron castings for re-melting in an electric furnace. (See page 2.)

[*To face page* 3.

any other changes in physical properties. If that event had taken place 100 years ago it would have been serious because it would have deprived mariners of the magnetic compass and thrown back the art of navigation to the condition in which it was some centuries previously. But if it happened to-day it would completely paralyse our modern life.

Electric trains and trams would cease to run, because all dynamos which generate the electric current that moves them would have become inert and useless. Electric lighting would vanish, and large towns would be left in darkness. Factories would come to a standstill because electric motors would have ceased to function. Telegraphs and telephones, electric bells and railway signals would be absolutely inoperative. All motor vehicles would be immovable because the magneto ignition or spark coil involves a magnet or electromagnet. Mechanical transport would therefore be impossible, and even main line steam railways could hardly work because the signalling arrangements on which they depend are essentially electromagnetic. No general strike on the very largest scale would more completely inhibit all commercial activity. In a month all large cities would be in a state of starvation and the traffic and movement on which our commercial life depends would be destroyed.

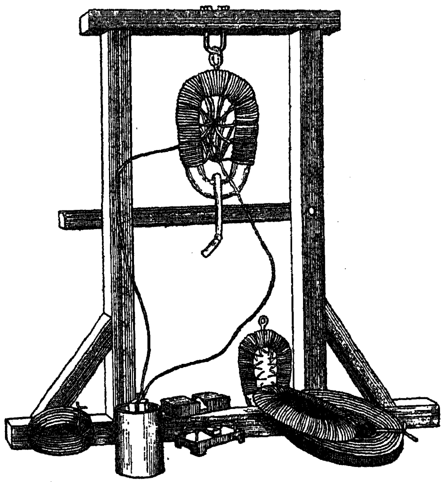


FIG. 2.—Joseph Henry's Electromagnets wound with many turns of insulated wire. Still preserved at Princeton College, U.S.A. He made the first electromagnets of this kind in 1828 and described them in the *Transactions of the Albany Institute.*

Suppose, then, that a committee of the Royal Society or of the Institution of Electrical Engineers found, after arduous researches, a means of giving back to masses of iron this special power of being magnetised. At once the frightful collapse of our business and domestic life would be at an end. Wheels would go round again, light reappear, railways and

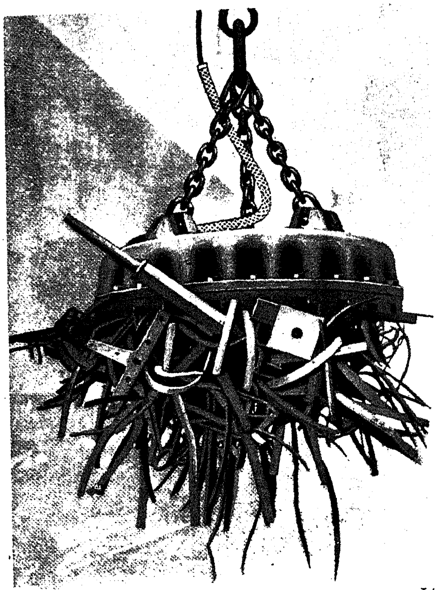
trams run, telegraphs and telephones operate, and the whole machinery of human intercourse be re-established. This supposed relief from an imaginary disaster may serve, however, to indicate the real benefits which the electrical engineer has conferred upon humanity, chiefly in the last fifty years. It is he who has provided the means for neutralising the effects of increase of population and its concentration in large cities by rapid electrical transit. He who has given the apparatus for quick communication of intelligence and intercourse between all portions of the habitable globe, and he who has brought us great comforts by providing improved methods of lighting, heating, ventilation and the transmission of energy.

Politicians are apt to think that their labours are essential to the prosperity of the community. They are, in truth, not nearly so valuable as the work of the electrical engineer. In fact, the legislative shackles which have been the politicians' work, such as the unwise Electric Lighting Act of 1882, or their treatment of the telephone, have frequently retarded seriously the work of the electrical engineer. That work has been of immense importance and it is desirable it should have more adequate appreciation. It seemed, therefore, possible that some slight service might be rendered to the general reader by giving a brief account of electrical engineering achievements during the last fifty years, presented in popular but not inaccurate language, drawn, to some extent, from the personal experience of the writer. The active and professional life of the author has been covered by the above-mentioned period of time, and it has been his good fortune to be closely and practically connected with the introduction of three great inventions, viz., the telephone, the electric incandescent lamp, and wireless telegraphy, into Great Britain. This experience brought him into close contact and often friendship with many of those eminent electricians and inventors whose names are now household words.

Reverting for a moment to elementary electrical facts the reader must be assumed to be familiar with the great invention of Volta in 1799 of the voltaic cell or primary battery, which gave us the first means of producing the electric current utilised in telegraphy (see Plate 4).

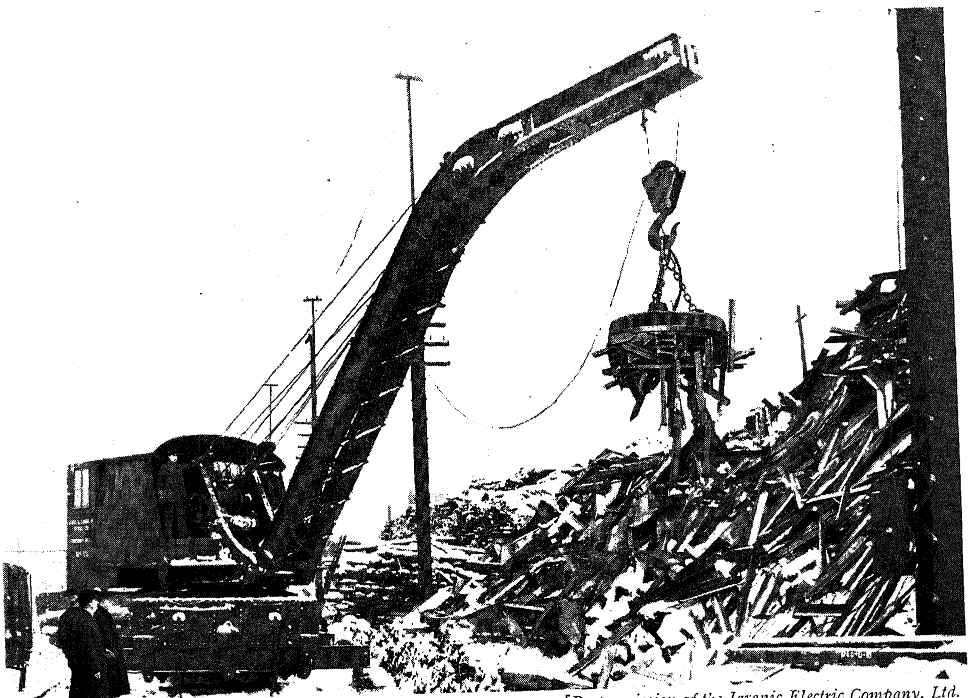
If a plate of zinc and a plate of copper are placed in contact they at

PLATE 3.



[*By permission of the Igranic Electric Company, Ltd.*

An Igranic Lifting Electromagnet handling Scrap Iron.



[*By permission of the Igranic Electric Company, Ltd.*

An Igranic Electromagnet at the end of a Crane lifting Scrap Iron into a Truck. A very difficult material to handle without this aid. (See page 2.)

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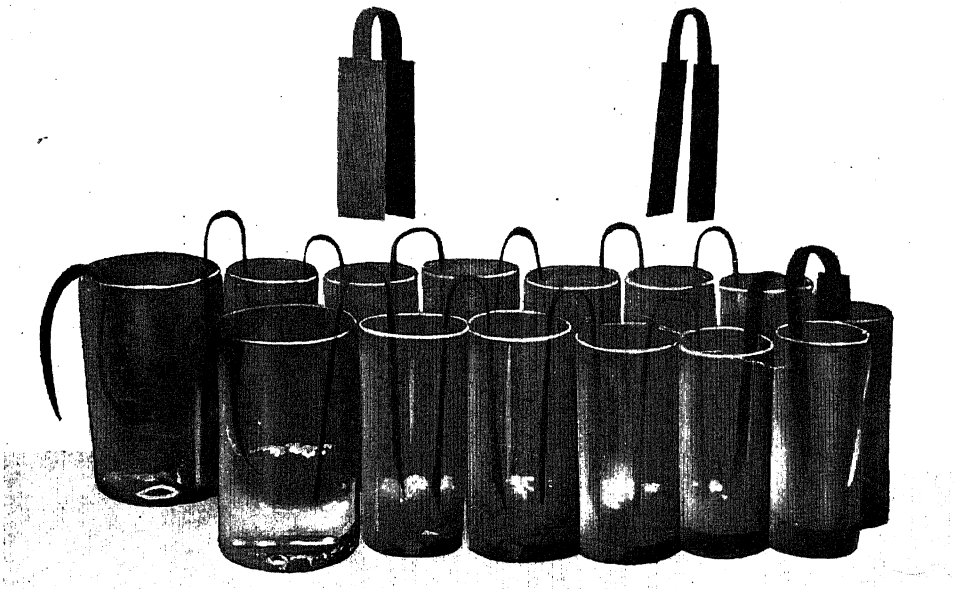

Volta's Original Voltaic Battery, or *Couronne de Tasses*. Above the battery is shown a pair of the copper and zinc plates which connect the cups. This was the first appliance for creating an electric current, and was invented by Volta about 1799. Unfortunately the whole of Volta's original electric apparatus was destroyed by a fire which took place at Como in July, 1899. (See page 4.)

once acquire a difference in electrical condition. The zinc becomes positively electrified and the copper negatively electrified. There is said to be a *difference in potential* between them, and this, in electricity, is analogous to difference of temperature in the case of heat.

If the zinc and copper plates are not in metallic contact but are both placed in a vessel of dilute acid, say sulphuric acid, they are brought nearly to the same potential. If, then, the two plates are connected by a copper wire outside the liquid we notice that bubbles of hydrogen gas make their appearance at the surface of the copper plate, whilst the zinc plate is dissolved away by the acid and forms sulphate of zinc. At the same time the connecting wire becomes hot and exhibits magnetic qualities (see Fig. 3). This arrangement is called a voltaic or galvanic cell. The wire is said to be traversed by an electric current and the cell is said to create an electromotive force. The exact source of this electromotive force was under discussion for the greater part of a century and forms one of the classic controversies of science. In the first paper read to the Physical Society of London at its inaugural meeting on March 21st, 1874, the author revived the discussion of this subject, but as it involves some considerable complexities very little need be said on it here.

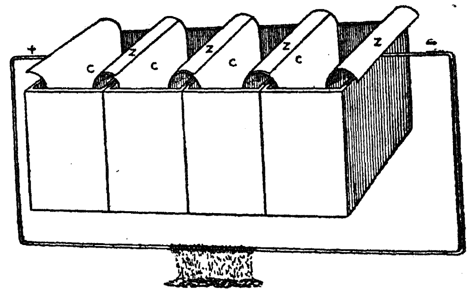

FIG. 3.—Plates of Zinc (z) and Copper (c) placed in Vessels of dilute Sulphuric Acid forming a Voltaic Battery. When the end zinc plate is connected to the end copper plate by a wire, this wire conveys an electric current and becomes magnetic. It will then attract iron filings, as it is shown doing in the illustration.

The Physical Society of London was formed early in 1874 by the late Professor Frederic Guthrie, and at its first meeting the founder invited the author of this book to read a paper "On the Contact Theory of the Galvanic Cell," describing some work recently done by the latter in Professor Guthrie's laboratory.

This paper is published at the beginning of Volume I. of the *Proceedings of the Physical Society of London.*

The difference of potential produced when two metals are placed in

contact is called their *contact potential difference*. In a voltaic cell with zinc and copper plates placed in dilute acid and connected by a copper wire a contact difference of potential is produced at the point where the copper wire touches the zinc plate. In the dilute acid there are atoms of hydrogen which are positively electrified. These are called positive ions. Other groups of atoms are negatively charged and are called negative ions. Hence, since the zinc is positively electrified it attracts the negative ions and unites with them, forming a soluble compound (say the sulphate) of zinc. The hydrogen ions move towards the negatively electrified copper plate, and though not able to combine with copper, take up negative electricity from it and are set free as gaseous hydrogen.

Volta constructed the first voltaic battery by placing a series of such cells together and joining the zinc plate of one cell to the copper of the next, and finally connecting the last copper to the first zinc by a wire external to the cell. The electromotive force is then multiplied to the same extent as the number of cells (see Plate 4).

Modern views as to the nature of the electric current and the physical effects taking place in the wire are discussed in Chapter VI. of this book.

Suffice it to say here that electric telegraphy is based upon two properties possessed by this wire when connecting the terminal plates of a voltaic battery. The wire then possesses the power of magnetising an iron bar, if wrapped round it, as already mentioned, and in the next place the wire has formed around it a state or condition in the circumjacent space called a magnetic field, because it influences a magnetic needle held there. This important fact was not discovered until twenty years after Volta had given his battery to the world, but it was first proved by H. C. Oersted, of Copenhagen, in 1820, a century ago. He noticed that a suspended magnetic compass needle always set itself when near a current-conveying wire so as to lie across the direction of the wire or at right angles to it, and the north pole of the needle deviated to one side when the wire was above it, and to the opposite side when the wire was below it (see Fig. 4).

Oersted correctly concluded that this was due to the current creating round the wire a magnetic field of force the direction of which was in

circles described round the wire, the planes of which were perpendicular to the wire.

The magnetising powers of the current and its generation by a battery are illustrated in the operation of the common or domestic electric bell. The batteries used for this purpose are made up of four to six (Leclanché) cells. Each of these comprises a glass pot in which is a solution of sal ammoniac or ammonium chloride. In the liquid stands a zinc rod and the place of the copper is taken by a carbon rod which stands in a porous clay pot packed round with peroxide of manganese. This cell gives an

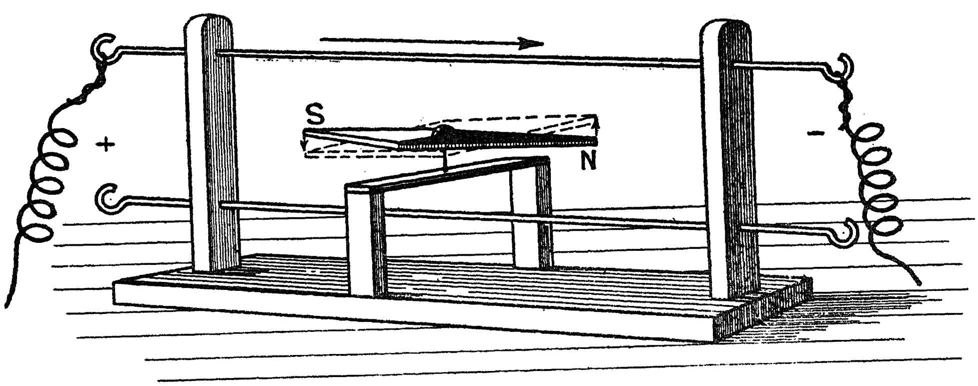

Fig. 4.—Oersted's Experiment, showing the influence of a wire conveying an electric current on a magnetic compass needle pivoted above or below it. This experiment was described by Oersted in a Latin thesis on July 21st, 1820.

electromotive force (E.M.F.) of 1·5 volts, and a more constant current than a simple zinc-copper voltaic cell.

The well-known trembling, or self-acting, electric bell was invented by John Mirand in 1850. An electric bell contains an electromagnet which, when energised by a current from a battery, attracts a piece of iron called the armature, to which is fixed a hammer which strikes a gong. The current arriving at the bell passes to a platinum-tipped screw which just touches the above-mentioned armature (see Fig. 5). The current then passes round the silk-covered wire of the magnet coils and then back to the battery.

When the magnet attracts the armature it interrupts the circuit at the

place where the screw touches the armature and the iron cores of the magnet then cease to be magnetic. The hammer is then drawn back by a spring and the circuit is completed again at the screw contact. Thus the hammer continues to vibrate and strike the gong as long as the pressure is kept up on the press button which closes the circuit at a distant place.*

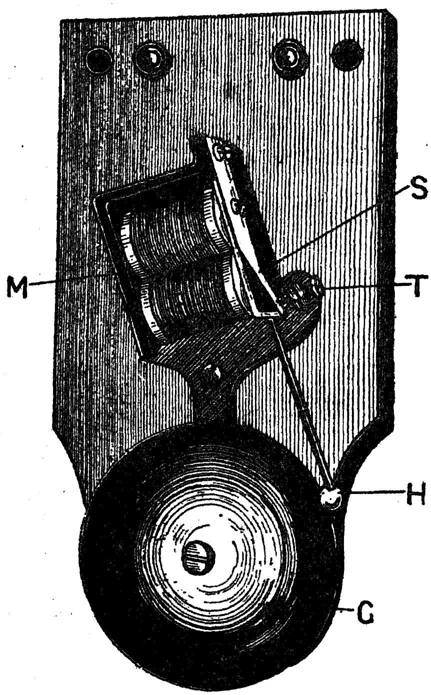

FIG. 5.—A Trembling Electric Bell as used in houses. The electromagnet M, when its coils are traversed by a current, attracts a strip of iron fixed flexibly at one end. This strip carries a hammer H, and, when attracted by the magnet, it strikes the gong G. This attraction causes an interruption of the circuit between S and T, and the magnet is demagnetised. The hammer then flies back, only to be attracted again.

The date from which we shall start our narrative, viz., 1870, was a period of importance in electrical invention. Prior to that date electrical engineering may be said to have been limited to telegraphy, land and submarine. Practical electric telegraphy in Great Britain dates back to 1837, the year Queen Victoria ascended the throne, when the first working electric telegraph was constructed by Cooke and Wheatstone, and laid down on a section of what is now the London and North Western Railway between Euston Station and Chalk Farm. A few years later (in 1843) a similar experimental line was laid down between Paddington Station and Slough by the same inventors and came into public notice by its effective service in aiding the capture of an escaping murderer.

The eminent railway director and chairman, Mr. James Staats Forbes, was interviewed by the *Daily*

* The intermittent self-acting current interrupter of an electric bell was adopted from a similar device previously used to interrupt the current of an induction or spark coil. Continental writers generally attribute the invention of this vibrator to J. P. Wagner, or to Neef, in 1839. These inventors,

Telegraph on September 30th, 1898, with reference to his recollections of the early days of railway engineering, and amongst other things he referred to the history of telegraphy.* He was asked about its first employment in connection with railway working and especially in the capture of Tawell.

In reply, Mr. Forbes said he had not been personally concerned in the arrest of Tawell, the Quaker, but he remembered the whole circumstances, and knew the railway officials well. Whereupon, though it was fifty-six years since the events occurred, he narrated the story of the first application of the electric telegraph to practical purposes. "I have the impression," he said, "and I am pretty sure I am right, that in one of the early numbers of *Punch* there was an illustration in which a man was seen in the gloaming, escaping from the scene of his crime, but the Recording Angel was depicted as throwing the lightning at him. It happened in this way. You must recollect old Gibbs, at Slough—he has not been dead very long—a great, big man, in green uniform, who used to cry, 'Slough, Slough, change here for Windsor!' It was he who suggested the use of the telegraph when the police came to him to learn whether the man in Quaker garb, reported to have been seen leaving the cottage of the woman who had been found poisoned, had left by train. There was no means of pursuit by special engine, and posting was out of the question. Tawell was on his way to London when the hue and cry was raised, and Gibbs thought of the telegraph. Cooke and Wheatstone had persuaded Brunel as to the merits of their invention, and he had induced the Great Western people to permit an instrument to be placed at Paddington terminus, with an experimental line to Slough. The telegraph office was in one of the arches, and it was open for a long time. The public, on payment of a

however, merely improved upon a similar device invented by C. G. Page, of Salem and Washington, in the United States, in 1838; but in which mercury cups were used instead of platinum-tipped screws as contact maker. It seems clear that MacGauley, of Dublin, also invented a form of self-acting electro-magnetic interrupter for an induction coil.

This simple device survives to the present day in every electric bell now used.

* The author was closely connected for about ten years, 1883–93, with Mr. J. S. Forbes, who was then chairman of the Edison and Swan United Electric Light Company, and also of the London Electric Supply Corporation, to both of which the writer acted as scientific adviser during the above-named period of time.

shilling, was permitted to send a message, which usually took the form of questions about the weather, and facetious folk used, by and by, to ask the operator at the other end how his mother was. The wire was not employed for railway work at all, and it was looked upon as a toy. When Tawell got away from Slough, Gibbs sent a message to Joe Collard, police superintendent at Paddington, describing the fugitive, and, to his surprise, the Quaker was requested to step into the police office when he alighted from the train. At the trial he was defended by Kelly, afterwards Baron Kelly, who ever after bore the nickname of 'Apple-pip Kelly,' because he set up the defence that the prussic acid, which it was suggested by the prosecution was the poison used, came from the pips of some very fine apples from a tree in the garden of the cottage where the deceased woman was living at the time of her death, and 'of which she was said to have eaten freely.'"

This unexpected use of a new invention is said to have stimulated greatly popular interest in the electric telegraph, with the result that it began to be regarded as an important addition to means of communication, and joint stock companies before long were formed to exploit it.

Although no one person can properly be said to have been the inventor of the electric telegraph, seeing that suggestions for such an appliance date far back to the earliest days of electrical discovery, yet for its introduction in a practically useful form credit belongs in a very large degree to Sir William Fothergill Cooke. He was the son of a professor of anatomy in the University of Durham, and in 1836 he was engaged at Heidelberg, in Germany, in making replicas in wax of certain anatomical models for his father. He had received no special training in physics or electricity, but when in Heidelberg he made the acquaintance of a certain crude form of electric telegraph produced between 1820 and 1832 by Baron Schilling, of Lanstadt. Mr. Cooke was struck with the possible importance of such an invention in connection with the development of railways then proceeding in England and elsewhere. He therefore devoted himself to the consideration of the subject and returned from Germany to England. Whilst he was working out the details of two telegraphic instruments to be tried on the Liverpool and Manchester Railway he was introduced by Dr. Roget to Professor (afterwards Sir) Charles Wheatstone (Plate 5), who

had also been giving much time to the subject, and the two entered into partnership in the matter. Cooke possessed, in addition to inventive ability, that business acumen and driving power which is necessary to convert scientific ideas or inventions into operative agents of public utility. Cooke and Wheatstone applied in May, 1837, for a British patent which was granted on June 12th, 1837, and a few days afterwards permission was obtained for an experimental installation on the London and Birmingham Railway between Euston Station and Camden Town.

The result of the tests on this line and on the Paddington to Slough line and other places created a demand for a public service, which began to be given a few years later by public companies.

In 1846 a joint stock company, called the Electric Telegraph Company, was formed to conduct commercial electric telegraphy in Great Britain. Soon other rivals appeared upon the field such as the Magnetic Telegraph Company, and later on the United Kingdom Telegraph Company and the London District Telegraph Company entered as competitors for the gradually increasing business of transmitting telegrams. In 1868 these companies owned between them over 16,000 miles of telegraph lines, and before that date the question of "nationalisation" of the telegraph had begun to be raised. By 1868 both political parties in the House of Commons were convinced that State ownership was desirable.

After protracted negotiation it was finally agreed that the terms should be twenty years' purchase of the profits of the year ending June 30th, 1868. The transfer and purchase was completed in 1870.

The first electric telegraphs in this country were "needle" instruments depending on the fact already mentioned, that if a wire conveying an electric current from a battery is laid parallel to, either over or under, a magnetic compass needle the latter will set itself at right angles to the wire, or at least endeavours to do so. The effect is enhanced if we wind many turns of silk-covered copper wire over and under a pivoted magnetic compass needle, the windings of the coils being parallel to the needle when no current flows (see Fig. 6). This modification of Oersted's experiment was first made by J. S. C. Schweigger about 1821, and was called a "multiplier" because it increased the effect of the current on the needle. If the needle is placed vertically with its axis of sus-

pension horizontal and the coil of insulated wire wound around it, the needle can be deflected to one side or the other by sending an electric current one way or the opposite way through the wire of the coil. In the original five-needle telegraph of Cooke and Wheatstone five such

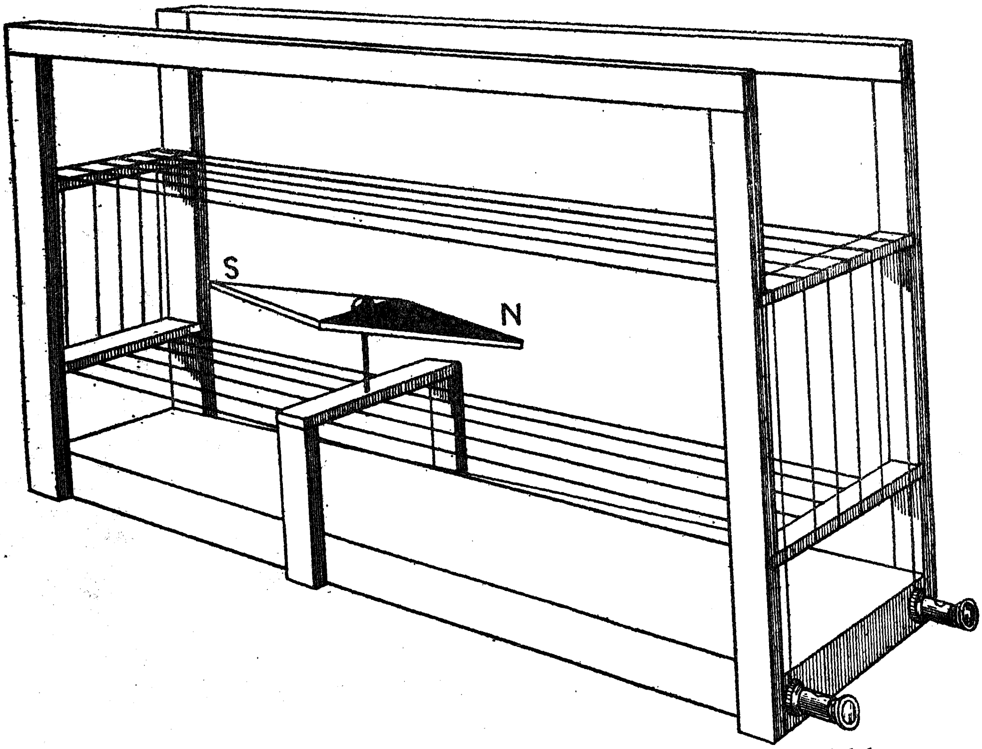

FIG. 6.—Schweigger's "Multiplier," in which a compass needle NS is surrounded by many turns of wire through which a current can be sent to deflect the needle. This apparatus was the first galvanometer, and formed the starting-point for the early forms of "needle" telegraph instruments.

magnetic needles and coils were employed, the current to operate each coil being conveyed by a separate line wire with an earth return. The signals were made by deflecting simultaneously two out of the five needles, so that their direction converged on to a particular letter of the alphabet painted on the dials (see Plate 6). This mode of signalling was

PLATE 5.

SAMUEL FINLEY BREESE MORSE.
(1791—1872.) (See page 16.)

SIR CHARLES WHEATSTONE. (1802—1875.)
A great inventor and scientific investigator. (See page 10.)

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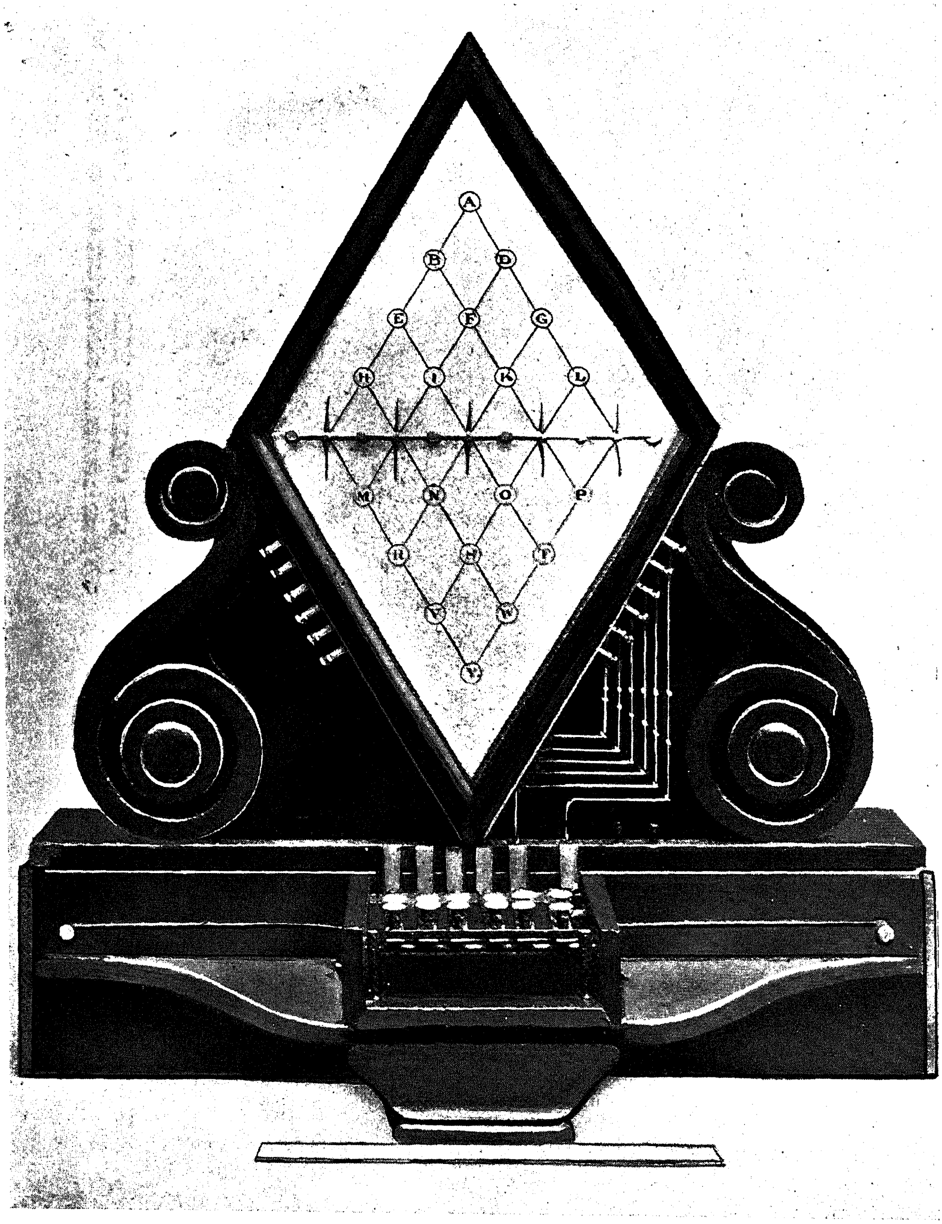
PLATE 6.



Cooke and Wheatstone's Five-needle Telegraph Instrument. A.D. 1837. (See page 12.)

[*To face page* 13.

naturally slow and the cost of laying the five-fold telegraph wire was considerable, and before long it was replaced by a two-needle instrument in which the signals were made by deflecting two needles simultaneously to right or left against two studs or stops and forming letters by suitable groups of deflections to right or left as is done in flag signalling. Like many other improvements this simplification was the result of an accident. A five-needle electric telegraph was being worked between Fenchurch Street and Blackwall Railway Stations when three out of the five wires broke down. The telegraph clerks ingeniously made up a code for working with the remaining two needles and worked it as quickly or better than with the five (Plate 7).*

Finally it was found that one needle was enough with a well devised code of signals, and the single needle telegraph is operated even to the present day.

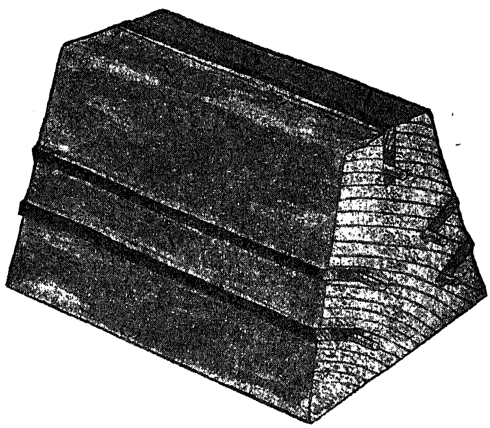


FIG. 7.—Photograph of a sample of Cooke and Wheatstone's original Five-wire Telegraph Line laid down in 1837 between Euston Station and Chalk Farm, London.

The construction of this simplest form of non-recording telegraph is as follows:—On the back of a vertical board which forms the face of the instrument are fixed two rectangular metal frames, on which many turns of silk-covered copper wire are wound. These coils are placed close together, but the interspace allows room for a steel axle which partly projects through a hole in the front board and pivoted at both ends. On this axle is fixed a bar of soft iron which is placed within the coils so as to be surrounded by the wire, and parallel to the long side of the coil. This piece of iron is kept magnetised

* About 25 years ago when some excavations were going on, a length of this five-wire Cooke and Wheatstone telegraph line was dug up between Euston Station and Chalk Farm, and on the occasion of Queen Victoria's Diamond Jubilee, in June, 1897, when a message was telegraphed by Her Majesty to all her peoples, a section of this first British telegraph line was interpolated in the circuit through which the Royal message was sent. In Fig. 7 is shown a sample of this line taken from a note on the subject by the late Sir William Preece in the *Journal of the Institution of Electrical Engineers*, vol. 26, p. 633, 1897.

by two permanent steel magnets placed outside the coil. The axle also carries a steel indicating needle, which is in front of the board, the deflections being limited by two ivory pins (see Plate 8).

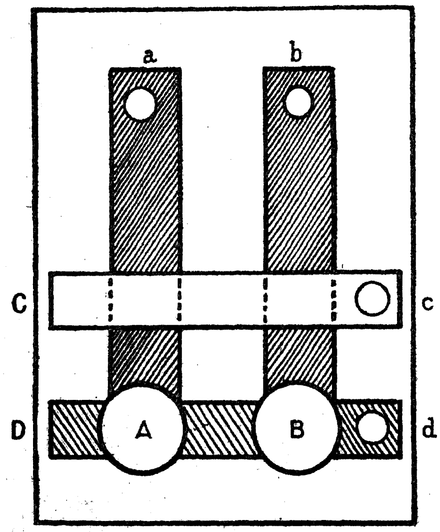


FIG. 8.—Simple form of Key or Tapper Commutator for reversing the flow of an electric current.

When an electric current flows through the coils in one direction it causes the iron magnet within the coil to deflect to one side as far as the stops allow, and if the direction of the current is reversed the deflection of the needle is to the other side. This coil and needle form the receiving part of the instrument. The same box or case contains also the means for sending out a current from a local battery into the line wire, or reversing its direction of flow at pleasure. This part is called the commutator or transmitter. In its simplest form it consists of two keys of metal partly faced with ebony like piano keys, which when depressed put one or other pole of the battery in connection with the line wire. In Fig. 8 A and B represent the two keys which are made of thin brass sheet and fixed at the ends *a* and *b* so that normally they press up against a horizontal brass strip *c*C, but these keys can be pressed down so as to touch another horizontal strip *d*D. To the ends of the strips *c*C and *d*D the terminal wires of a voltaic battery are attached. In electrical diagrams a battery is always represented by alternations of thin and thick lines standing respectively for the carbon plate or positive (thin line) and the zinc plate or negative (thick line) poles of the voltaic cells, such as Leclanché, of which it is composed.

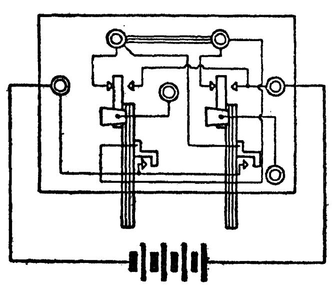
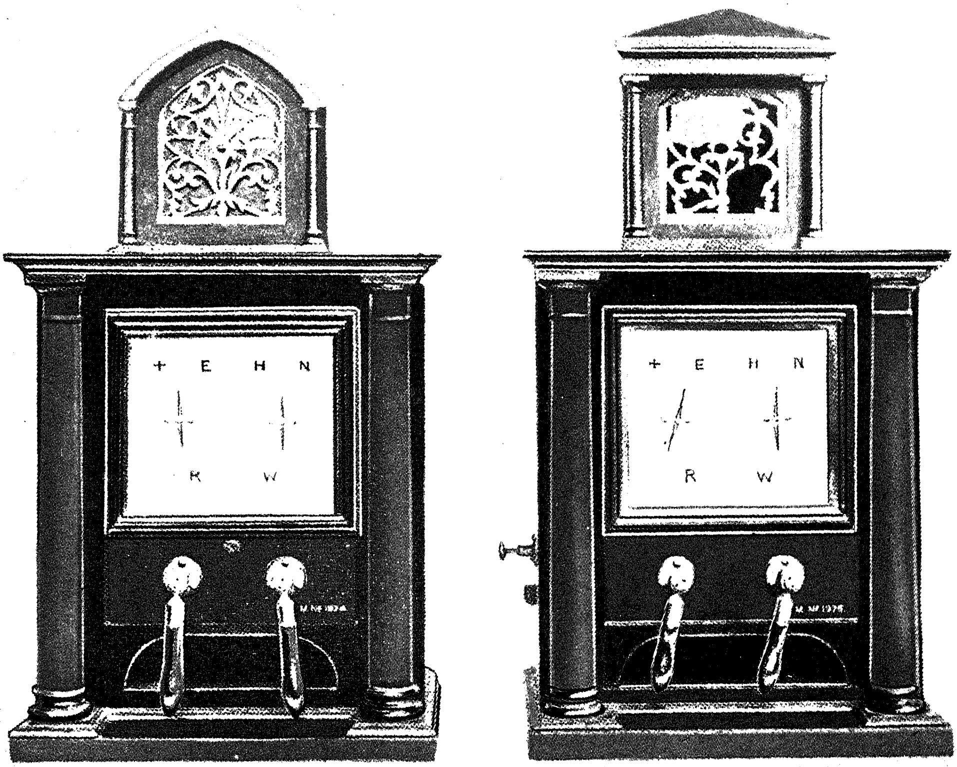


FIG. 9.—Diagram of Connections for the Tapper Commutator.

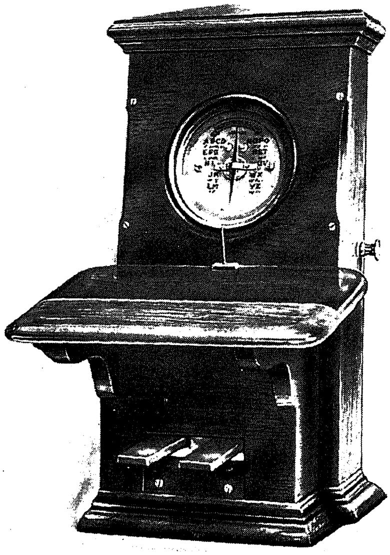
PLATE 7.

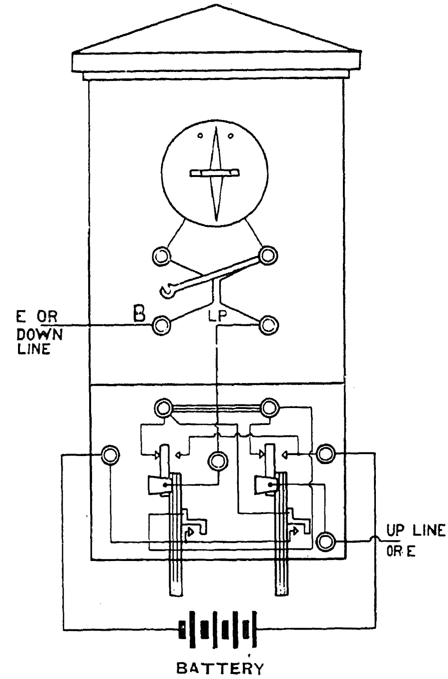


Cooke and Wheatstone's Two-needle Telegraph Instrument. A.D. 1837. (See page 13.)

[To face page 14.

PLATE 8.





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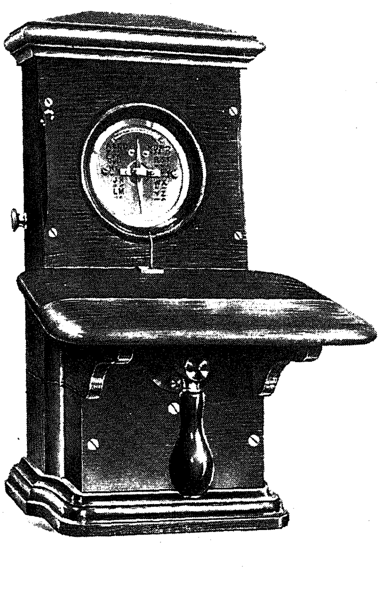
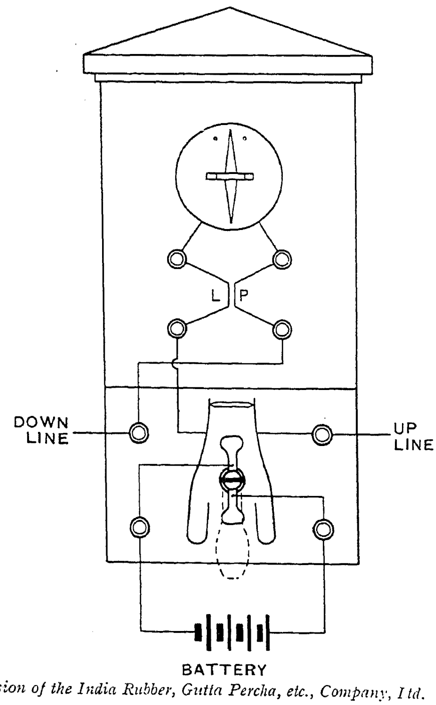
Single-needle Telegraph with Key or Tapper Commutator. The skeleton diagram on the right shows the connections. (See page 14.)





[*By permission of the India Rubber, Gutta Percha, etc., Company, Ltd.*

Single-needle Telegraph with Drop-handle Commutator. The skeleton diagram on the right shows the circuit connections to the local battery and the up and down line. (See page 16.)

[*To face page* 15.

One of the keys, say B, is connected to a wire joined to a plate sunk in the earth or to the waterpipes of a house. The second key A is attached to the one end of the receiving coil of the instrument, the other end of this coil being connected to the line wire which runs to the distant receiving instrument. The battery has its two poles connected to these cross bars. It will be seen that if the key B is pressed down it puts, say, the negative or zinc pole of the battery to earth, whilst the A key connects the positive pole with the line. A current, therefore, flows out through the receiving coil of the home instrument and the line and passes through the receiving coil of the distant instrument, and then flows to earth and back again to the battery. Professor Steinheil, of Münich, in 1838 made the great discovery that no return wire is needed to bring the current back provided both ends of the line are connected to plates of metal sunk in the earth. This "earth return" is used in nearly all cases in modern telegraphy. If the A key is pressed down then a negative current flows from the battery into the line and the needle of the receiving instrument will be deflected in the opposite direction. Hence, by tapping one or other of the keys the needles of the home and the distant receivers are deflected to one side or the other, and strike sharply against the ivory stops. The actual form of tapper commutator used in telegraphy is not quite so simple, but a view of the real instrument and its connections is shown in Plate 9.

An alphabet is then constructed as follows: A deflection of the needle to the left is called a *dot* signal and a movement to the right is called a *dash* signal.

The International telegraph alphabet is built up of two such signals taken one, two, three or four at a time in a certain sequence. The space between letters corresponds in duration to that of a *dot* signal and the space between words to three times this duration.

The International Telegraph Alphabet.

A	– ——	E	–
B	—— – – –	F	– – —— –
C	—— – —— –	G	—— —— –
D	—— – –	H	– – – –

I	– –	R	– —— –
J	– —— —— ——	S	– – –
K	—— – ——	T	——
L	– —— – –	U	– – ——
M	—— ——	V	– – – ——
N	—— –	W	– —— ——
O	—— —— ——	X	—— – – ——
P	– —— —— –	Y	—— – —— ——
Q	—— —— – ——	Z	—— —— – –

Full stop – – – – – –
Understand – – – —— –

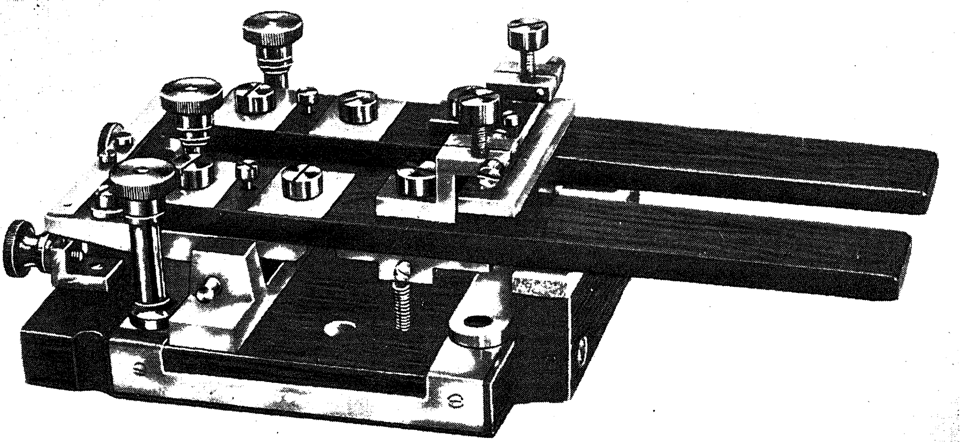
In the single-needle telegraph a movement of the needle to the left followed by one to the right signals the letter A, and one to the right followed by three taps to the left, the letter B, etc.

In place of the double key commutator earlier types of single-needle instrument had a transmitter worked by a single pendant handle, movements of which to left or right sent positive or negative electric currents through the coils of home and distant receivers (see Plate 8).

The advantages of this simple form of telegraph are (1) its ease of manipulation—an operator can easily learn to send with it at the rate of twenty words per minute; (2) the small current required—about 5—10 milliamperes is sufficient; and (3) a number of such instruments can be arranged in series so that operating one transmitter indicates the message on all the receivers on the same line. The disadvantages of it are that it makes no record of the message, and that it taxes the attention and fatigues the receiving operator more than forms of receiver which appeal to the ear.

Whilst Cooke and Wheatstone and their associates were engaged in developing electric telegraphy with the needle instruments in England, another inventor, Samuel Finley Breese Morse (1791–1872) (see Plate 5) was occupied in a similar enterprise in the United States of America. It is curious that neither Morse nor Cooke, the two pioneers of practical electric telegraphy, had received any systematic education in electrical science. Morse by profession was an artist, and in 1829 went to Europe to study the old Masters in European picture galleries.

PLATE 9.



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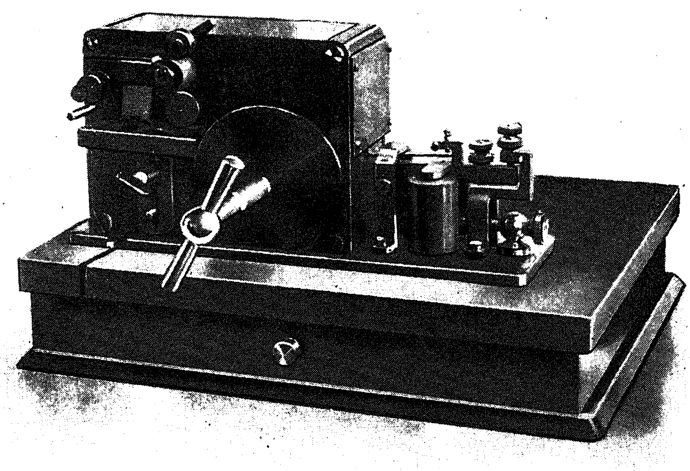
Actual form of Tapper Commutator used with the modern Single-needle Telegraphs. (See page 15.)

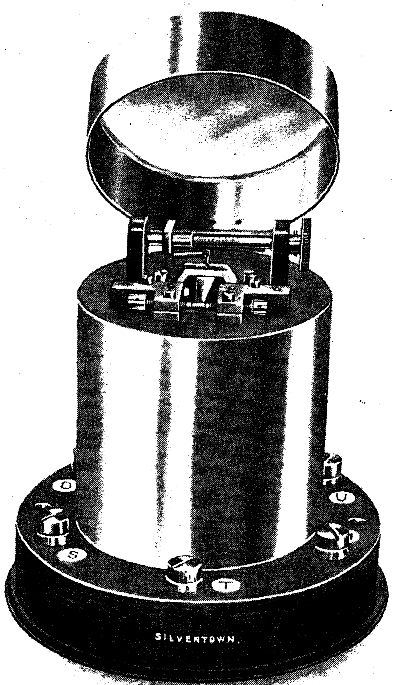


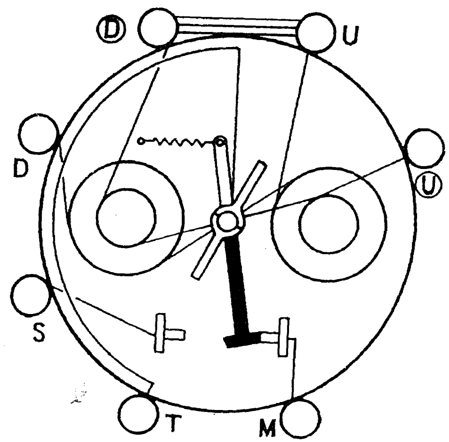
[*By permission of the Automatic Telephone Manufacturing Company, Ltd.*

A view of a modern Morse Inker or *dot* and *dash* Recording Telegraph. (See page 17.)

[*To face page* 16.

PLATE 10.





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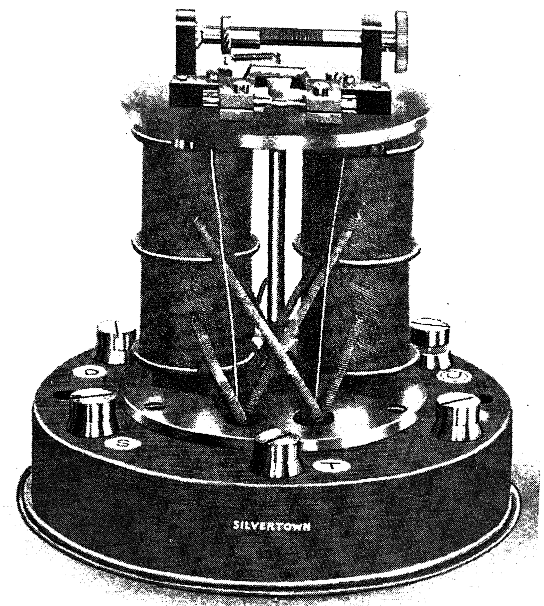
A Telegraph Relay: General Post Office Pattern. D is the end of the electromagnet winding connected to the down line, and U that to the up line. T is the connection to the "tongue" (black bar) of the relay, and S and M the relay contacts at which the local circuit is closed.



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Another view of a Telegraph Relay with cover removed, showing the Electromagnet of the Relay.

[*To face page* 17.

On the return voyage in 1832 a chance conversation on the subject of the electromagnet invented by Sturgeon suggested to Morse a train of thought as to the use of the electromagnet to create signals at a distance. In a few days he had completed a rough draft of an apparatus for that purpose. He had, however, a long struggle with many difficulties before he could embody his ideas in practical form, and it was not until September, 1837, that he was able to exhibit his apparatus working to various friends in New York.

The idea which formed the basis of his invention was that an electromagnet at a distance supplied with current from a battery at the sending station could be made to attract a piece of iron, called an armature, at pleasure by simply closing the electric circuit by means of a contact key at the sending station held down for a short time. The attraction of this magnet on the armature was made, by means of the lever, to press a metal point against a strip of paper moved by clockwork so as to indent the paper with short marks (dots) or long marks (dashes) according to the time the current was kept flowing through the coils of the electromagnet by the pressure on the key at the sending station.

In modern forms of instrument the indenting point is replaced by a little metal wheel which revolves partly immersed in ink. This wheel is pressed up when the electromagnet is energised by a current and makes a mark on the paper strip of length depending on the time the magnet is kept excited. In this form it is now called a Morse inker. In Plate 9 is shown a view of the instrument itself, and in Fig. 10 an outline elevation.

The telegraph paper is cut into strips ½ inch wide and provided in the form of long, flat rolls, kept in a drawer in the instrument base. From this place it is drawn by a clockwork motion so as to pass under a brass drum. The inking wheel is carried on the end of a lever at the other extremity of which is a soft iron armature. When the latter is attracted by the electromagnet the ink wheel is pressed up against the paper and marks a line long or short (—— or –) according to the time the magnet is kept energised (see Fig. 11). The play of the armature is limited by two adjustable screws.

Although Morse exhibited his telegraph in operation in 1837 it was not

until May, 1844, that it was put into actual practical operation between Washington and Baltimore. The first message sent by it is said to have

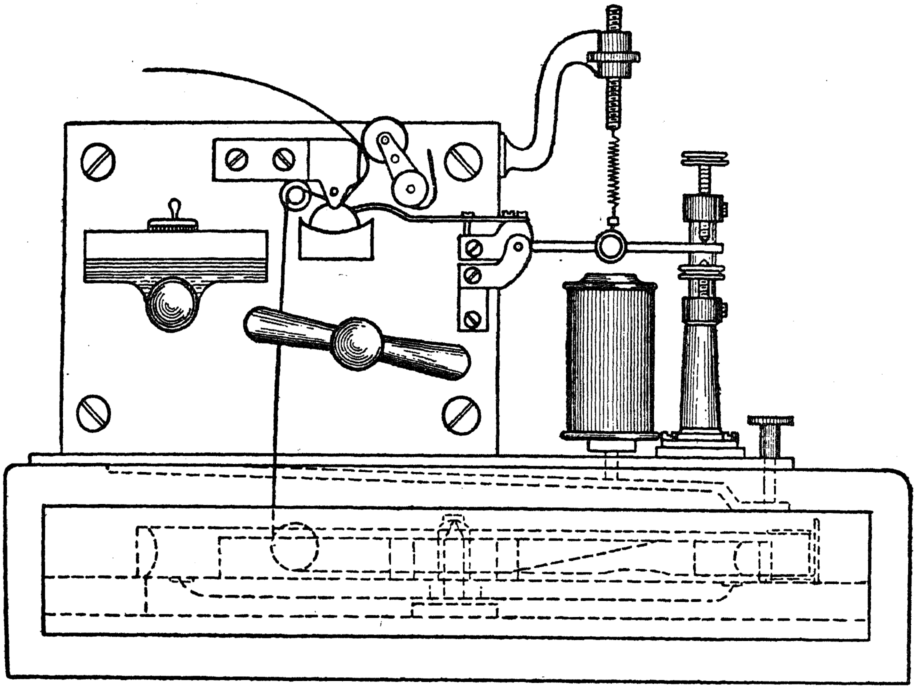


FIG. 10.—Outline Elevation of a Morse Inker. In a drawer in the box on which the instrument is fixed is a roll of paper tape, which is drawn by clockwork over the ink wheel, and on this the *dot* and *dash* signals are recorded.

been suggested to Morse by his mother, viz., the text "What hath God wrought" (Numbers XXIII. 23).

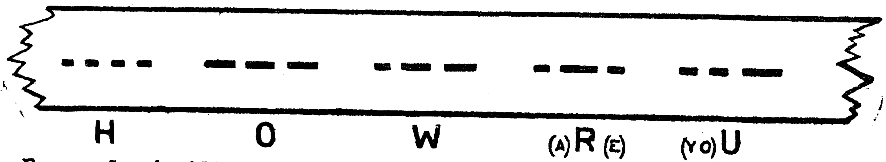


FIG. 11.—Sample of Morse Paper Tape, showing *dot* and *dash* signals as made by the inker.

A difficulty which presented itself at an early stage in practical telegraphy was the leakage of electricity from the line.

In the first practical telegraphs the line wire was put underground. Gutta-percha-covered copper wires were laid in troughs of creosoted wood covered with a metal lid, or else the wires were drawn into glazed earthenware pipes.

The expense of these underground conductors was considerable, and as methods of detecting electrical faults were then rudimentary the cost of eliminating defects was large.

Hence by 1842 most of the railway telegraphs and those telegraph

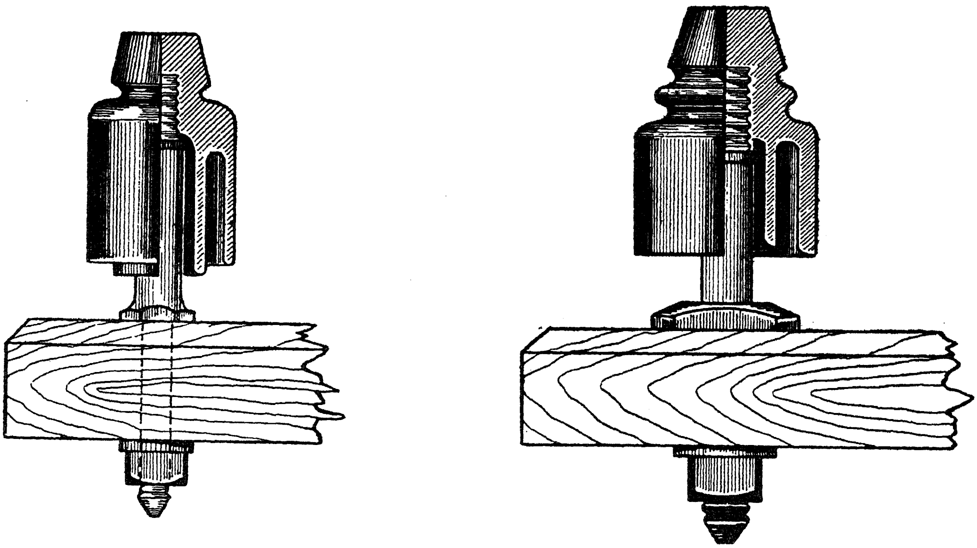


FIG. 12.—A view and half-section of a Glazed Porcelain Telegraph Insulator with double Petticoat. It is fixed by an iron bolt to the cross-arm on the telegraph post.

wires which ran along railways were aerial lines, the wires being carried on porcelain or glazed stoneware insulators fixed to cross-arms on tall posts from 20—40 feet high.

Rain, however, wetted the outside of the insulators and caused leakage of electric current to earth.

In course of time improved insulators were designed, called double or triple shed insulators. Such a device consists of a sort of bell of best highly glazed porcelain having double or triple bottom edges (see Fig. 12), so that the inner upper portions keep fairly dry. The telegraph wire is

bound to the outside of the insulator and the latter is carried on an iron bolt fixed to a wooden cross-arm on the post. At one time iron telegraph wires were much employed on account of cheapness, but the material now mostly used is hard-drawn copper or bronze wire, as that material has about six times the electric conductivity of an iron wire of the same size and does not decay by rust.

Even with the best insulators there is a leakage of electricity from the

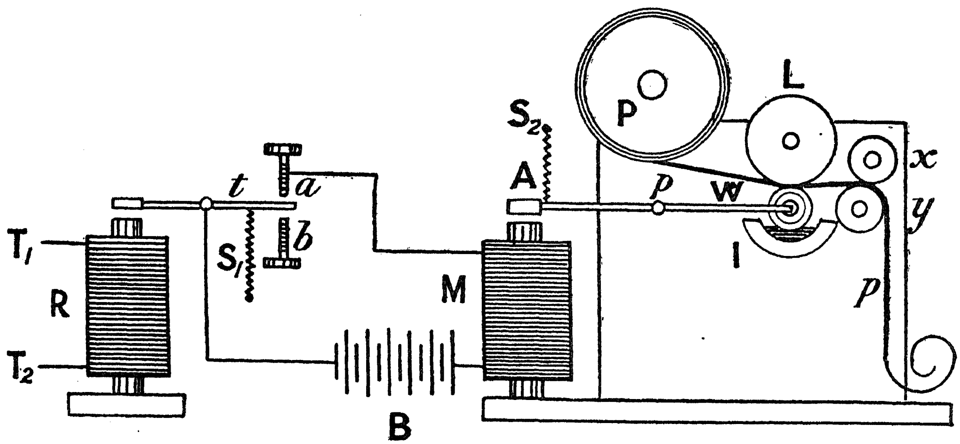


Fig. 13.—A diagram showing the Connections between a Morse Inker and its Relay. M, the electromagnet of the inker. A, the armature which, when drawn down, presses the ink wheel W up against the paper strip P. R is the relay magnet which, when energised by a feeble current, presses the tongue *t* up against the contact screw *a*, and this permits the current from the local battery B to actuate the magnet M.

line and the current is weakened also by the electrical resistance of the wire which dissipates energy.

It was therefore found that some means was required to re-enforce the electric energy of the feeble current arriving at the receiving end of a telegraph line, and Morse solved the problem by the invention of the telegraph *relay* or *repeater*. In its simplest form this consists of an electromagnet R (see Fig. 13) the coils of which are wound with many turns of wire so as to be energised by a feeble current. The magnetising effect of the coil is proportional to the product of the number of turns of wire in the coil and the strength of the current flowing through it. Hence many turns compensate for feebleness of current. This electro-

magnet attracts a soft iron armature fixed to the end of a pivoted lever, so that when the armature is drawn to the magnet the other end of the lever *t* makes contact with an adjustable screw *a* and completes or closes the circuit of a local galvanic battery B and the electromagnet M of a Morse telegraph instrument (see Fig. 13). Hence the function of the relay is to enable the feeble electric current coming out of the line wire, too feeble to work the telegraph signalling instrument directly, to operate a sensitive electromagnet, which in turn actuates the recording instrument by the aid of a local battery which supplies the energy. In the first relays made by Morse the electromagnets were enormously heavy and large, the reason being that he had the idea the magnet must be wound with wire of the same diameter as the telegraph wire itself.

In course of time this was seen to be a mistake, and in a modern telegraph relay the magnet is small and wound with many turns of fine wire and not larger than can be carried in the pocket (see Plate 10, page 17).

About 1850 the Morse recorder was introduced into Great Britain.

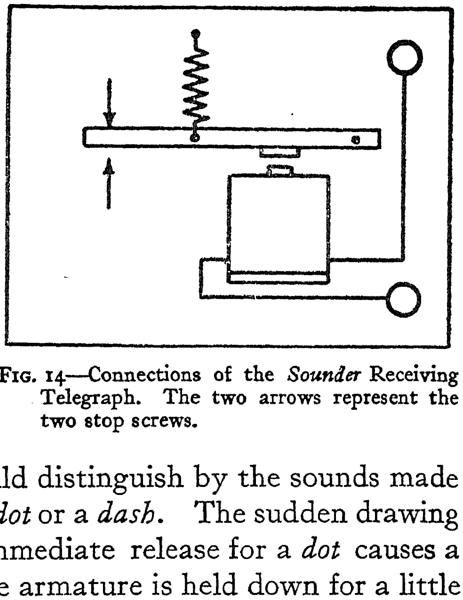


FIG. 14—Connections of the *Sounder* Receiving Telegraph. The two arrows represent the two stop screws.

Telegraph clerks using the Morse recorder in the United States of America very soon found that they could distinguish by the sounds made whether the instrument was printing a *dot* or a *dash*. The sudden drawing down of the armature and its almost immediate release for a *dot* causes a sharp sound like a click. But when the armature is held down for a little time, as in making a *dash* signal, there is a decided difference in the sound due to the fact that a longer interval elapses between the armature striking the two screws on its downward and upward motion (see Fig. 14). It was found quite easy, therefore, to read the Morse code signals by ear. This method is far less fatiguing than following the movement of a " needle " by eye as the ear is more automatic in its action. The receiving instrument was therefore reduced to a very simple form. It comprised only an

electromagnet, the coils of which were traversed by the line wire current, and the attraction and release of the armature caused two well recognisable sounds separated by a short or long time interval, corresponding to the *dot* and *dash* signals. The receiving instrument was then reduced merely to an electromagnet and an iron armature attracted by it which played between two stopping screws. In this form it is called a *sounder* (see Plate 11). Electric telegraphy was hence reduced to its simplest elements. At the sending station is a battery and a key by the light pressure of the finger on which for a brief instant or a little longer the sender transmits the Morse code signals. At the receiving end is the electromagnet or "sounder," and the receiving clerk reads off by the "clicks" the signals being sent. Sounder instruments can transmit at the rate of thirty words or so per minute, and the receiving clerk has both hands and eyes free to write down the letters read off by ear.

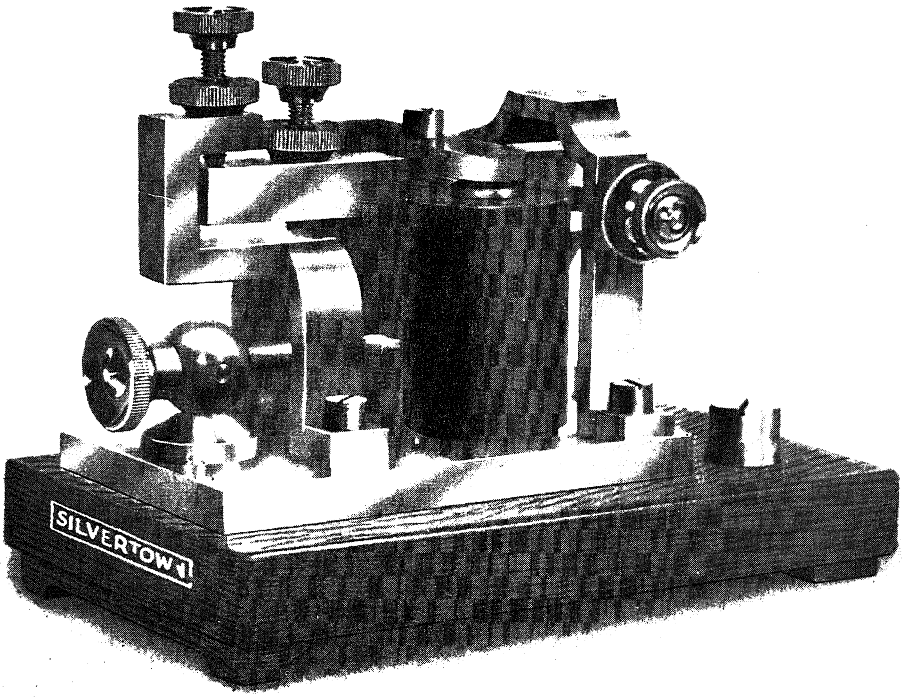
Some operators acquire amazing skill in sounder working and its simplicity renders it a very favourite telegraphic instrument in the United States.

There were some cases in which electric telegraphy was required to be worked by perfectly unskilled persons, as between railway stations and on private lines, and this led, prior to the invention of the telephone, to the introduction of A B C or dial instruments, in which a pointer moving round a dial pointed in turn to the letters of the alphabet engraved on its circumference as determined by the operator at the sending station.

We may explain how this can be done by a description of a simple lecture apparatus. At the transmitting end suppose a metal toothed wheel having the interspaces between its teeth filled up with insulating material. Let there be twenty-six teeth and twenty-six spaces corresponding to the twenty-six letters of the alphabet. Suppose two springs M, N to press against this wheel so that as the wheel is turned round the spring makes and breaks electrical contact with the wheel (see Plate 12). Let a current from a battery Q pass from the spring to the wheel and thence from the bearings on which the axle of the wheel rotates let the current pass into the line wire, and at the receiving end let it pass through the coils of an electromagnet and then return by the earth.

If, then, the wheel is rotated through one complete revolution twenty-

PLATE II.



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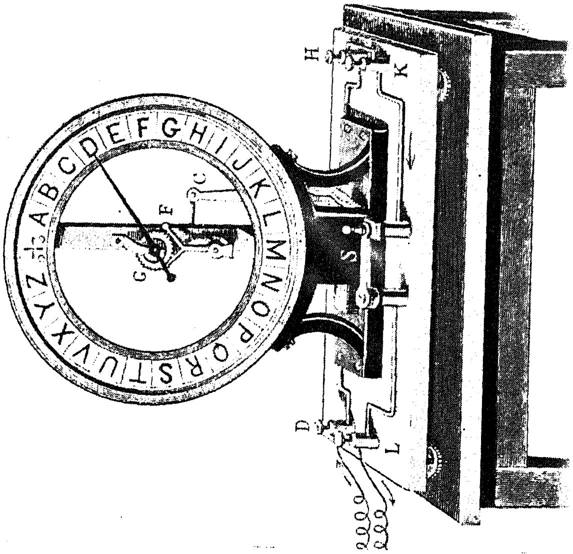
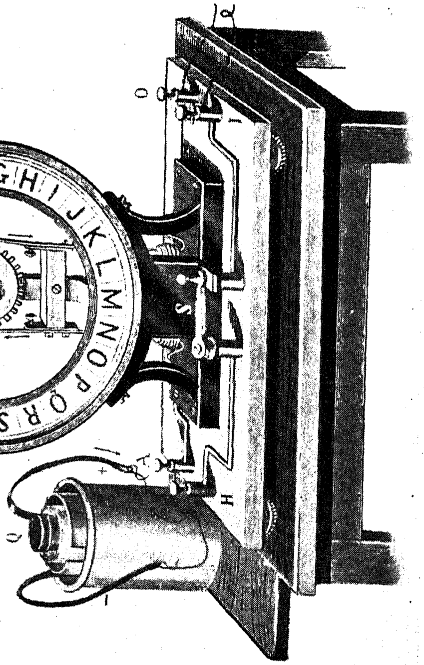
A Telegraphic *Sounder* Receiving Instrument for Signalling by Sound. (See page 22.)

[*To face page* 22.

PLATE 12.



Simple form of A B C Telegraph Receiver.



Simple form of A B C Telegraph Transmitter.

[*To face page* 23.

six times during the rotation the current will flow out for a short time as each tooth passes over the spring contact, and will energise the distant electromagnet.

Let a pointer attached to the wheel move round against the letters of the alphabet engraved on a fixed plate behind it (see Plate 12). Imagine, then, that at the receiving station there is a metal wheel G with teeth cut like the escapement wheel of a watch and let the armature of the electromagnet have attached to it a rod ending in a pawl which engages in the teeth of the wheel so that when the armature is attracted the pawl pulls the wheel round through the space of one tooth and when it is released the pawl goes forward freely and then engages in the next tooth.

Let the escapement wheel have twenty-six teeth. It is then evident that if we turn the toothed wheel round at the transmitting station it sends out into the line a series of interrupted electric currents and these actuate the magnet and pull the escapement wheel round through a number of stops equal to the number of the intermittent currents. Let the escapement wheel have an index needle and let the twenty-six letters of the alphabet be engraved on a face plate round the escapement wheel. Suppose, then, that the index needles on both transmitter and receiver are set to point at the zero or at the same letter of the alphabet. If the sender turns his wheel through a space equal to four teeth and stops, say, at the letter D, four brief electric currents will be sent into the line, and the receiving wheel will be drawn round by the pawl through a space equal to four teeth, and also stop at the letter D.

In this way, by turning the pointer of the transmitter to point successively to various letters on the dial, always moving in one direction, the index of the receiver will follow the motions of the transmitter and words and sentences may be slowly spelt out. In actual practice the instrument is somewhat more complicated than the above rudimentary apparatus.

A certain type of dial instrument was invented in 1840 by Sir Charles Wheatstone and may be briefly described as follows (see Fig. 15). The intermittent electric currents required are not obtained from a battery but are generated by the rotation of a coil of copper wire, wound on an iron core or shuttle, between the poles of a permanent magnet. It was one of Faraday's most important discoveries that a coil of wire so rotated

between the poles of a magnet has an electric current created in it. This discovery is the basis of all modern dynamo electric machines for the generation of electric currents by mechanical power. The current so created is an *alternating* current, that is, it flows in one direction during one half turn of the coil and in the opposite direction in the other half turn. The coil of wire is wound on a shuttle-shaped iron core and the axle on which it turns is geared with reduction to an index needle so that it requires fifteen turns of the axle to rotate the pointer through a complete revolution. During this time fifteen positive and fifteen negative currents are sent out into the line wire. Around the lower dial over which the pointer moves are thirty keys marked with the twenty-six letters of the alphabet, and certain other signs much used, such as (o zero), (+), (—), (. full stop) (see Fig. 15).

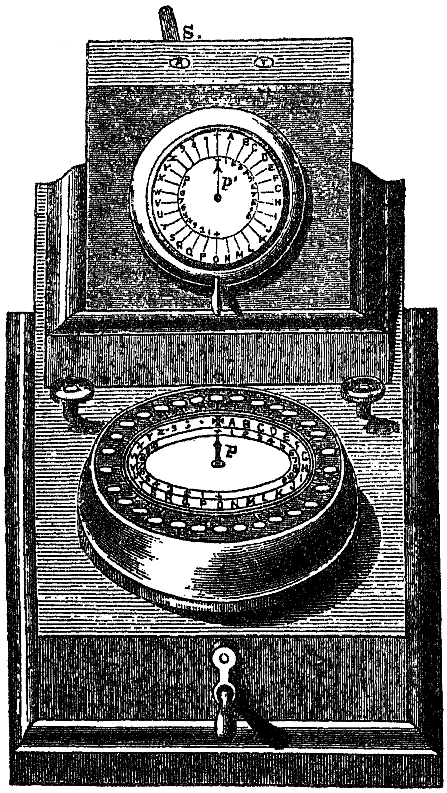


FIG. 15.—Wheatstone A B C Telegraph. The handle at the front, when steadily turned round, generates the alternating electric currents which operate the receiver at the distant place.

The internal arrangements are such that if the handle rotating the coil of wire is steadily turned, and a key on the dial then pressed, the alternating currents pass out into the line all the time the pointer is moving from zero up to that letter engraved on the key. Thus suppose that the key marked L is pressed down: L is the twelfth letter of the alphabet. Hence, six positive and six negative currents would be sent out into the line, but would then cease until the key marked L was raised and some other key pressed down.

By an ingenious arrangement the keys are all so connected together

by a loose chain that the pressing down of one key raises any other key which may have been previously depressed. In other words, it is impossible to have two keys pressed down at the same time (see Fig. 16).

The receiving instrument contains an electromagnet through the coils of which the alternating current from the transmitter flows. Between its poles is situated the end of a magnetised steel lever. This is attracted to one pole or the other according to the direction of flow of the current. This lever carries at the other end an escapement wheel having a pointer attached to its axis. This wheel has fifteen teeth and there are fixed

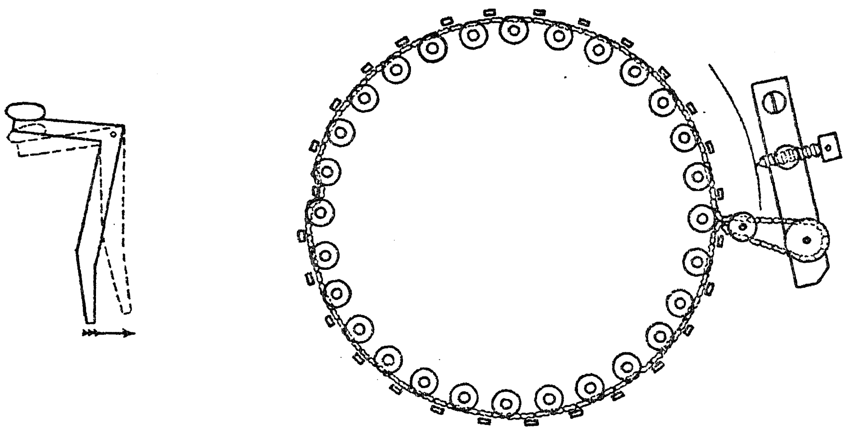


FIG. 16.—The Endless Loose Chain connecting all the Keys in the Wheatstone A B C Transmitter, so that only one key can be depressed at a time.

pawls or pins so placed that as the escapement wheel rocks to and fro it is compelled to rotate, passing through a space of one tooth at each complete oscillation or complete period of the alternating current. The pointer attached to this wheel moves over a face plate round which are engraved the letters of the alphabet. This needle moves in step with the pointer on the transmitter dial and stops when it stops (see Fig. 17).

Hence, words and sentences can be spelt out if the sender continually rotates his current generator and then presses the letter keys one by one in the proper order. The receiving instrument needle then steadily rotates, but pauses for an instant at the letter signalled to enable the receiver to read and record it.

Although the A B C instruments enable any one without code training to send a telegraphic message it was felt at an early stage in the development of the art that the ideal form of receiver would be one which prints down the message in Roman type, and accordingly ingenious minds were directed to its invention. One of the most interesting of these is the printing telegraph invented by David Edward Hughes (1831–1900) (Plate 13), a London-born man and a great genius, whose early life was spent in America, where he became professor of music and of natural philosophy in the College of Bardstown, Kentucky. In 1884 he removed to Louisville to supervise the manufacture of his remarkable printing telegraph by which he made both fame and fortune.* The United States patent for this invention was secured in 1855, and its success was immediate and extensive.

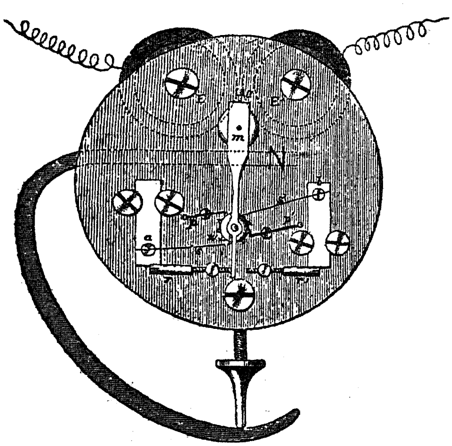


FIG. 17.—The Mechanism of the Receiving Portion of the Wheatstone A B C Telegraph.

All previous printing telegraphs had been based on the escapement wheel or step-by-step motion and

* Professor D. E. Hughes was a great inventor, as shown by his printing telegraph, his invention of the microphone (described in Chapter II.), and of other instruments, such as the induction balance and sonometer. He very nearly anticipated some of the discoveries which led to wireless telegraphy. He was also a charming companion and most genial man. At his death he left funds for the endowment of several science scholarships and for the donation annually of gold and silver medals and a premium by the Royal Society of London for electrical discoveries and inventions, irrespective of nationality or sex. The medallists so far have been :—

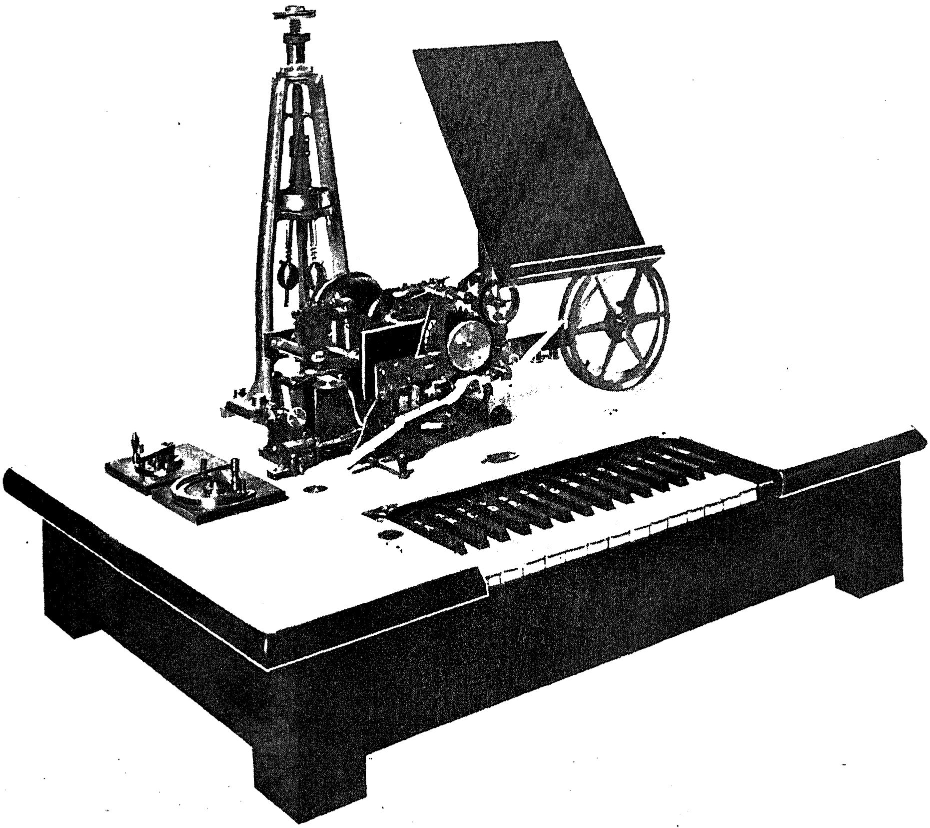
1902 Joseph John Thomson.
1903 Wilhelm Hittorf.
1904 Sir Joseph Wilson Swan.
1905 Augusto Righi.
1906 Mrs. Hertha Ayrton.
1907 Ernest Howard Griffith.
1908 Eugen Goldstein.
1909 Sir Richard Tetley Glazebrook.
1910 John Ambrose Fleming.
1911 Charles T. R. Wilson.
1912 William Duddell.
1913 Alexander Graham Bell.
1914 John S. Townsend.
1915 Paul Langevin.
1916 Elihu Thomson.
1917 Charles G. Barkla.
1918 Irving Langmuir.
1919 Charles Chree.
1920 Owen Willans Richardson.

PLATE 13.

DAVID EDWARD HUGHES. (1831—1900.)
Inventor of a printing telegraph and of the microphone, and other valuable electrical instruments. (See page 26.)

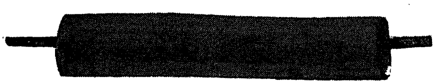
[*To face page* 26.

PLATE 14.

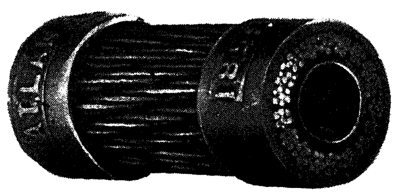


[*By permission of the General Post Office.*

Perspective view of the Hughes Type Printing Telegraph.



A photograph of a sample of the First English Channel Cable laid by the Brothers Brett in 1850. It is merely a copper wire thickly covered with gutta-percha. (See page 34.)



Photograph of a sample of the 1858 Atlantic Cable. (See page 37.)

[*To face page* 27.

were made by clockmakers. Hughes introduced the free running type wheel and special means of synchronising the wheels at both stations.

His machine (see Figs. 18, 19, and Plate 14) had a keyboard like that of a small piano having fourteen white and fourteen black keys, each

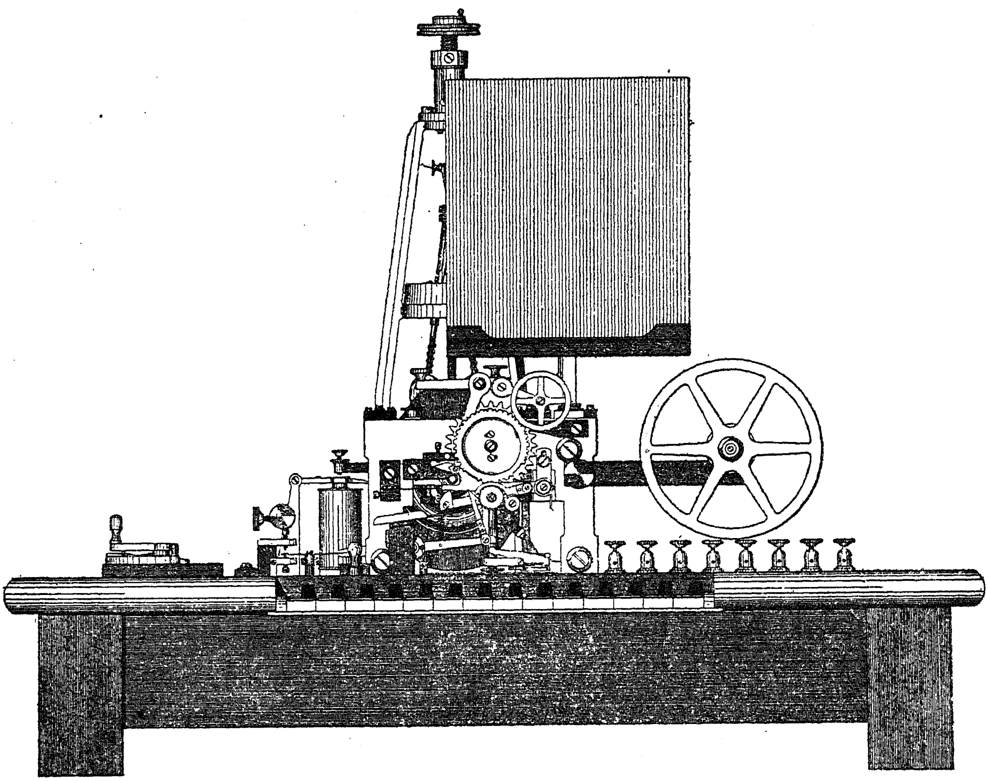


FIG. 18.—Elevation of the Hughes Printing Telegraph. It has a keyboard like a small piano, and, by the pressure of the finger on these keys, the letters of the alphabet and numerals are transmitted electrically and printed on paper by the distant receiving instrument.

standing for a letter of the alphabet, for a full stop and for a blank or space respectively.

The broad general principle of the machine is as follows:—It contains a type wheel on the edge of which are engraved the letters and digits, and this wheel is kept inked with printers' ink by a roller. Beneath the wheel a strip of paper is drawn which at certain instants is pressed

up suddenly against the type wheel by a cam, and this prints on it a letter.

The power required to drive the type wheel and press up the paper is derived from powerful clockwork or from an electric motor when electric supply is available. The speed of this type wheel is controlled

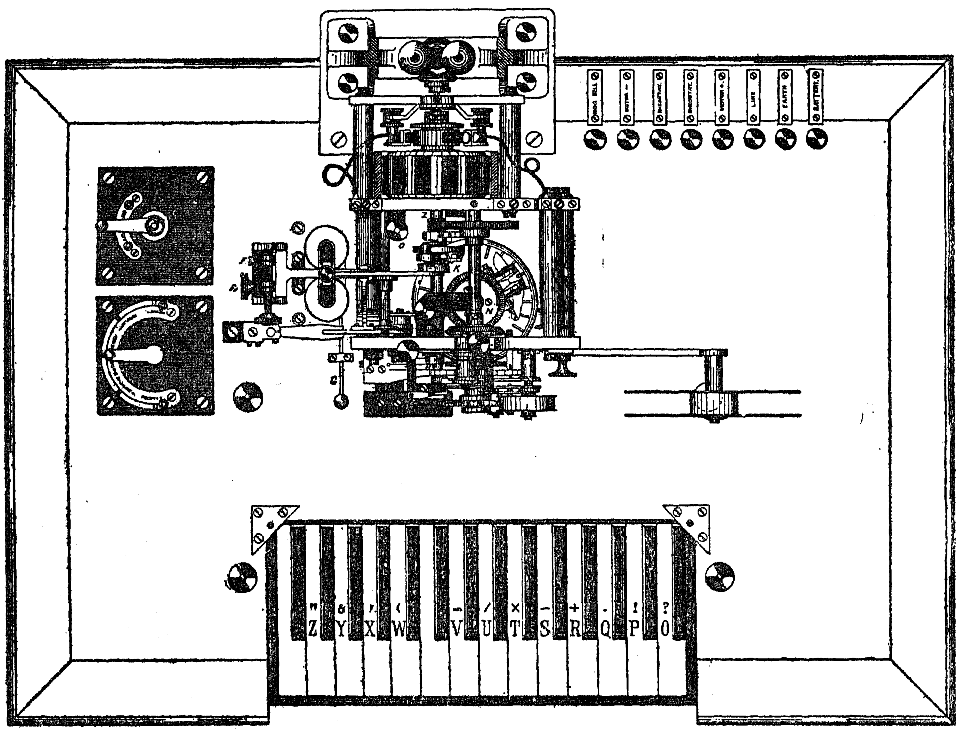


Fig. 19.—Plan of the Hughes Printing Telegraph, showing the Piano-like Keyboard.

by a very sensitive form of governor, so that it runs at a perfectly uniform speed.

Moreover, the type wheels at the sending and receiving stations not only run at exactly the same speed, but run in step, so that if the paper strips at both stations are pressed up at the same instant the same letter of the alphabet will be printed on both.

There is an ingenious device by which the gain or loss of step of the

type wheel is continually corrected. Turning, then, to the transmitting portion of the instrument; each key on the board when depressed raises a corresponding pin in a set of twenty-eight pins arranged in a circle. In the centre of this circle is a vertical axis which carries a radial arm ending in a piece of metal called a chariot. If none of the pins are raised, the chariot does not touch them, but if a key is depressed and a pin raised, the chariot in sweeping round makes grazing contact with the top of the pin and closes an electric circuit. Each key on the board is marked with a letter of the alphabet, and hence each pin stands for a particular letter. Accordingly, if the keys are touched in succession, so as to spell out words, the contact of the chariot and corresponding pins sends out into the line brief electric currents equal in duration but unequally spaced apart in time.

The shaft which carries the chariot arm is also geared to the type wheel, so that when a key is pressed and a pin is raised, the corresponding letter on the type wheel is over the strip of paper and is printed on it by a mechanism which suddenly raises the paper at that instant. Moreover, owing to the synchronism of the type wheels at the home and distant stations the same letter is in a position to be printed at both stations at the same moment. This printing is set in motion by the brief electric current sent into the line at the instant when the chariot makes contact with a raised pin.

The mechanism for doing this is a novel form of magnet. Instead of using the current to energise a soft iron electromagnet, Hughes employed it to weaken the poles of a permanent steel magnet and release an armature.

On the poles of a powerful steel magnet are fixed soft iron rods wound over with insulated wire, and over the ends of these pole pieces is a soft iron armature, which is attracted and held down. When a current flows through the coils it weakens their magnetisation by inducing in them a contrary polarity, and the armature is forced off them by a spring. In so doing it strikes a lever which is made to do several things—

(i.) Press up the paper strip against the type wheel and record a letter.

(ii.) Then move forward the paper so as to be ready for a fresh printing.

(iii.) Synchronise the type wheel or adjust its position.

(iv.) Engage a cam which replaces the armature on the magnet, ready to respond to another brief current.

The instrument prints in Roman type on the paper slip any message sent, and it does this by intermittent, brief, single currents of about half to one milliampere in strength (see Fig. 20).

It is possible to record three or four letters per revolution of the chariot arm and a speed of 220 letters per minute can be obtained, equal to about forty words a minute. The speed of working on cable circuits is greater than that of the sounder. The Hughes printer is very extensively used on the Continent, but in Great Britain its use is confined to a few Continent cable circuits and some other lines where there are many coded messages. It was widely employed in America soon after its invention in 1855, and one reason for its success was the free-running

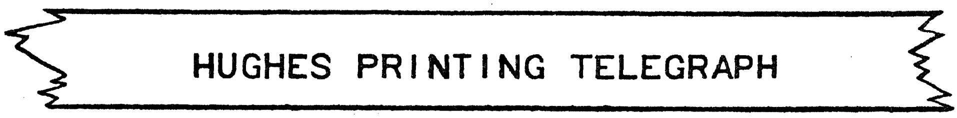


Fig. 20.—Sample of Paper Tape with Letters printed on it by the Hughes Type Printing Telegraph.

isochronous type wheel which printed each letter by the action of a single feeble electric current without arresting the rotation of the wheel. Moreover, the machine was substantially built, so as to withstand constant hard usage without failure, and this implied the most careful design and selection of material.

A problem which confronted early telegraphic engineers was that of making use of a line to send simultaneously messages in opposite directions along it. At one time it was considered a hopeless quest, but the first approximation to a solution was found in 1853 by J. W. Gintl, of Vienna, and in the following year by Frischen, Siemens and Halske, of Berlin. The first to give a really practical solution was J. B. Stearns, of Boston, U.S.A., in 1868. There are two methods generally employed, one called the differential relay, and the other the bridge method.

For any really successful method of duplex working it is essential

that the actual line shall be balanced against an artificial line, which is an electrical copy of it.

A telegraph line possesses two qualities of importance. It has *resistance*, in virtue of which the energy of currents flowing along it is dissipated and the current weakened. It also possesses *capacity*, in consequence of which it stores up electric energy in the form of an electric charge. Approximately speaking, we may say that a telegraph line resembles a water pipe which has to be filled with water before any will flow out at the other end, and this flow is accompanied by a decrease in water pressure along the pipe, owing to the pressure taken up in forcing the water along

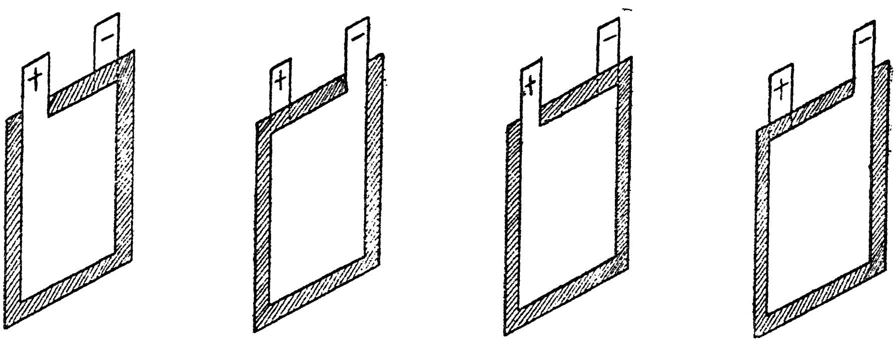


FIG. 21.—The Plates of an Electrical Condenser, consisting of sheets of paraffined paper having sheets of tinfoil placed on both sides. The paper sheets are the shaded portions in the diagram.

it. The essential condition of duplex working is that the outgoing electric current must not affect the receiving instrument at the home station, but must affect the receiver at the distant station.

This can be done by employing a relay, the electromagnet of which is wound with two separate wires. One end of each wire is connected to the centre of a sending key. The two wires are wound in opposite directions round the cores of the electromagnet, so that when the key is pressed the outgoing current has two paths to go by, viz., along one wire to the line and along the other wire to an artificial balancing line consisting of a resistance to the ends of which are attached the terminals of a condenser. This condenser consists of sheets of paper saturated with paraffin wax, interposed between sheets of tinfoil not quite so large as

the sheets of paper. When a pile of alternate sheets of tinfoil and paraffined paper has been built up, every alternate tinfoil sheet is connected together. This is done by making the tinfoil sheets with a lug or tag long enough to project beyond the paper sheets, first on one side and then on the other (see Fig. 21). The tinfoils on similar sides are then clamped together. The arrangement virtually forms a Leyden jar or

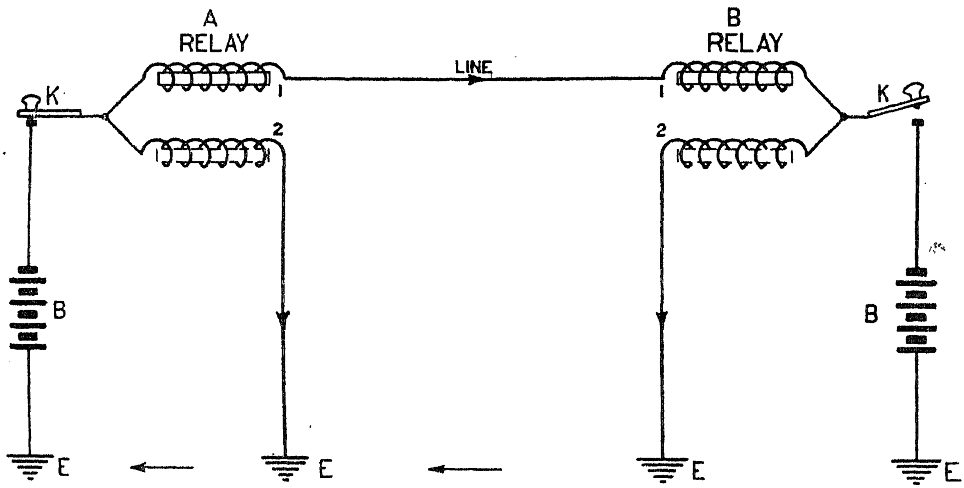


FIG. 22.—Diagram to illustrate the Principles of Duplex Telegraphy employing a Differential Relay at each end of the Line. When the key K (on the left) is depressed, the current from a battery B (on the left) flows through two wires which are wound in opposite directions round one iron bar. (*N.B.*—For the sake of clearness the windings are shown on two bars, 1 and 2, but these are actually a single bar.) Hence the relay magnet at the sending end A does not operate. But at the receiving end the current flows in the same direction round the two windings, and hence the relay magnet at B does operate. The artificial or balancing line is the line 2E. The letter E denotes a plate sunk in the earth, called an earth-plate.

reservoir of electricity, and can be adjusted to have any required *electrical capacity* measured in units called *microfarads*.

The capacity and resistance of the artificial line have next to be adjusted to imitate those of the real line. The artificial line is then earthed at one end.

It will be seen from the diagram in Fig. 22 that the home relay is not affected by the two outgoing currents, one flowing into the actual line and the other into the artificial line (denoted by the lines 2E in the

diagram), because these equal currents flow in opposite directions round the magnet of the relay.

But the incoming current does affect the relay, because it flows to earth through the two wires wound on the relay in such directions as to co-operate in magnetising action upon it.

Maron in 1863 devised the bridge method of duplex working. For

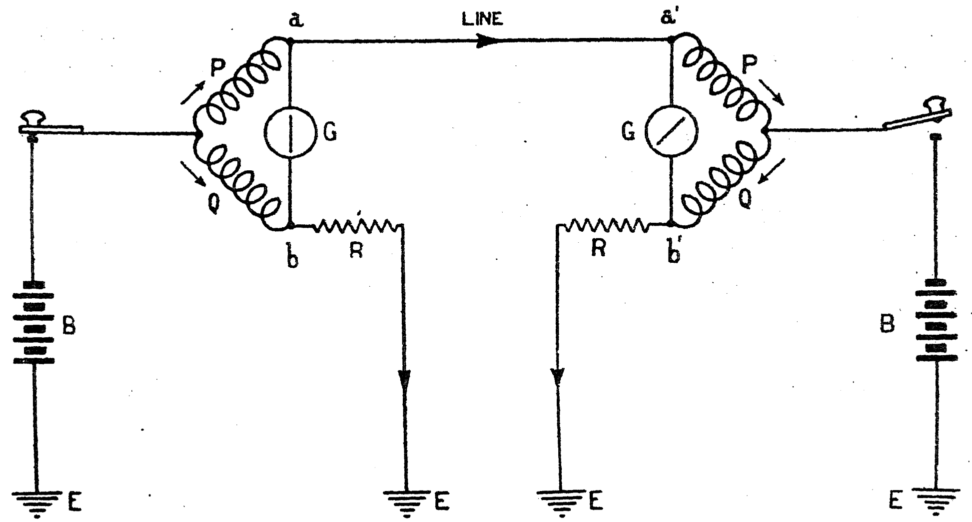


FIG. 23.—Diagram to illustrate the Principles of Duplex Telegraphy employing the Bridge method of working. When the key on the left is depressed, the current from the battery B flows through the two equal resistances P and Q, and is equally divided between the telegraph line *aa'* and the artificial line RE. Hence the telegraph instrument G at the sending station (on the left) does not operate. But at the receiving station the current flows as shown by the arrows, and so operates the receiving instrument G. The letter E denotes a plate sunk in the earth, called an earth-plate.

this the outgoing current splits between two equal resistances, to the far ends of which the terminals of the receiving instrument are attached. Then from one terminal proceeds the actual line and from the other the artificial equating line R, the end of the latter being earthed (see Fig. 23). When the key is depressed to send a signal, the home receiving instrument is not affected, because the electric potential at its terminals *a b* is exactly equal. At the receiving end the current flows to earth through the receiving instrument and through the artificial line, and as this flow is in

such directions (shown by the arrows in the diagram) as to make the terminals $a' b'$ different in potential, the receiving instrument G operates. Signals can therefore be sent simultaneously from both stations. The result of duplexing a line by either of the above methods results in doubling its capacity to transmit messages, because each operator at the two ends can transmit as he pleases, regardless of the fact that a message may at that moment be coming to him.

Hardly had land telegraphy been established on a practical basis than electricians had begun to consider the possibility of laying a wire under the sea.

The pioneers in this latter enterprise were Jacob and John Watkins Brett, who registered a joint stock company on June 16th, 1845, for telegraphic communication between England and France. In 1850 they laid a simple gutta-percha-insulated copper wire across the Straits of Dover, and although there is evidence that a few messages were transmitted through it, it lasted, ephemera-like, but a single day before it was broken.*

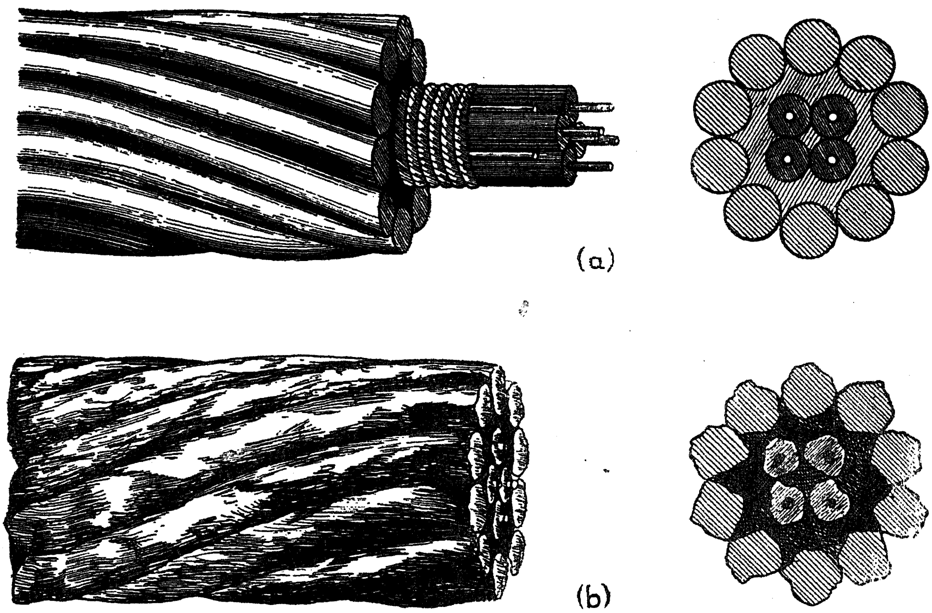
A celebrated railway engineer, Mr. T. R. Crampton, then offered financial assistance, and also passed on the suggestion of a colliery engineer to "armour" the fragile gutta-percha-covered copper wire by winding it over with hemp and over that with spiralised iron or steel wires (see Fig. 24). Such a cable was duly made and laid across the Straits of Dover in September, 1851, by him, and in November, 1851, public messages were transmitted through it. This type of submarine cable, with some improvements, has endured to the present day. Gutta-percha as an insulator remains for long periods very perfect provided it is immersed in water and kept in darkness, and is mechanically protected, as by the armour, from injury.

This success started into existence the submarine cable industry, which has always been particularly a British industry. Cables were then made, laid, and sometimes lost in various places in the world, and large experience thereby gained. In 1857 the project of an Atlantic cable came before the public, fostered and promoted by a wealthy and far-

* The author possesses a sample of this first Channel cable laid by the Bretts (see Plate 14, page 27), which was given to him by Sir John Rotton, having been taken from the steamer which laid it.

seeing American, Cyrus W. Field. It was a huge step from the short cables then already laid to the submergence of a telegraph cable 2,000 miles long in water nearly three miles deep. As usual, there were pessimists who predicted failure and said it could not be laid, or if laid, could not be used.

The promoters of the scheme, however, consulted Faraday, asking



[*By permission of Sir Charles Bright.*

FIG. 24.—Photograph of a sample of the Armoured Submarine Telegraph Cable laid across the English Channel, September, 1851. The four central circles are the sections of the insulated copper wire, and the ten outer circles are the steel armour.

whether a signal could be sent through such a long cable. Faraday had already considered and experimented on the subject, and explained in an article in the *Philosophical Magazine* for June, 1854, that a gutta-percha-covered copper wire laid in the earth or sea was, in fact, a very large Leyden jar of which the copper was the inner coating, the gutta-percha the insulator or dielectric, as Faraday called it, and the sea-water or earth the other conductor. He found that such a cable, when insulated at both

ends, could be charged and discharged like a Leyden jar. This led him to the conclusion that a time element would enter into the question and that the current would not appear at the distant end in its full strength at once.

The question was, however, taken up by William Thomson, afterwards Lord Kelvin (see Plate 15, page 32), then a young professor of natural philosophy at Glasgow University and perhaps the greatest mathematical, physical and inventive genius that Great Britain has produced, hardly even excepting Sir Isaac Newton himself.* Thomson, as a young student, had been greatly attracted by the elegant and powerful mathematical methods which the great French analyst, Joseph Fourier, had developed for dealing with the problems of the propagation of heat in conductors. Thomson saw that the problem of the propagation of an electric current in a submarine cable, when expressed in mathematical language, was exactly the same as that of the propagation of heat along a metallic wire one end of which is for a short time raised to a high temperature.

In May, 1855, Thomson communicated to the Royal Society of London a celebrated classical paper "On the Theory of the Electric Telegraph,"

* William Thomson, Baron Kelvin, was born at Belfast in 1824. He entered Glasgow University as a student at ten years of age, and graduated at Cambridge as Second Wrangler and First Smith Prizeman in 1845 at the age of twenty-one. Even as a boy and undergraduate he was the author of original papers on mathematics which astonished his tutors. When only twenty-two years of age he was called to occupy the Chair of Natural Philosophy in the University of Glasgow, a chair which he adorned by his genius, inventions and discoveries for fifty years.

His noble and elevated character, genial and attractive disposition, the astonishing originality, range and profundity of his thought, caused him to be revered and loved by an immense circle of pupils, acquaintances and friends.

He was for forty years or more regarded as the acknowledged leader of British science on its physical and mathematical side. His great inventions in telegraphy, his magnetic compass and sea-sounding apparatus, brought him fame and fortune. He was knighted in 1866 for his share in laying the Atlantic cable, and in 1892 raised to the peerage as Baron Kelvin of Largs. He died on December 17th, 1907, and his mortal remains were laid in Westminster Abbey side by side with those of Sir Isaac Newton.

The author was privileged to enjoy his personal acquaintance for many years, and had much correspondence with him at one time on electrical measuring instruments. To the very end of his life Lord Kelvin took the most vivid interest in new scientific advances. Almost the last occasion when he appeared at the Royal Institution, London, where he himself had so frequently lectured, was when he took the chair at a Friday evening discourse on "Recent Contributions to Electric Wave Telegraphy," by the author, on May 24th, 1907, and he was so interested in certain experiments shown that he lingered long at the lecture table repeating them again for himself after the lecture was concluded.

His biography was admirably written by the late Professor S. P. Thompson.

in which he gave a full discussion of the subject and solved the problem completely.

An explanation of his work can hardly be given in non-mathematical language, but the author has as far as possible simplified the treatment for the benefit of engineering students in his book on *The Propagation of Electric Currents in Telephone and Telegraph Conductors* (Constable & Co., London).* In his paper, Thomson showed that there is, properly speaking, no definite speed of propagation of a signal in a submarine cable, but that its apparent velocity depends upon the square of the length of the cable and upon the electrical resistance and capacity per mile, and upon the nature of the receiving instrument.

When a battery is applied to one end of a long cable the electric current does not appear at the distant end in full strength at once but rises up gradually as shown by the ordinates or heights of a curve called a curve of arrival (see Fig. 25). The time which elapses before it reaches a certain strength capable of affecting a given receiving instrument varies as above stated as the square of the length. That is to say, if the cable is made twice as long, all other things remaining the same, the current will take four times as long to take effect on the receiver, and the signalling will, therefore, be only one quarter as fast.

Returning, then, to the actual achievement, the story of the Atlantic cable has often been told and never better than by Sir Charles Bright, a son of Sir Charles Tilston Bright, who was the engineer of the great enterprise.†

Briefly recapitulated, the facts are these. In 1857 a sufficient length of armoured submarine cable was made to span the Atlantic, and the scheme was to divide the cable between two ships, a United States cruiser, *Niagara*, and a British vessel, H.M.S. *Agamemnon*. These were to join the cable in mid-Atlantic and then sail in opposite directions, paying out the cable between them. Failure, however, attended the first attempt in 1857. In 1858 more cable was made, and after several failures the laying

* See Chapter V., third edition, 1919. This book is a reproduction of courses of University Lectures given by the author on this subject in 1910–12.

† See *Submarine Telegraphs*, by Sir Charles Bright, F.R.S.E. (Crosby, Lockwood & Co., London). See also his *Life of Sir Charles Tilston Bright*.

of this cable was completed and Great Britain and the United States telegraphically united on August 5th, 1858 (see Plate 14, page 27).

The electricians who had charge of the arrangements for signalling had, unfortunately, conceived the idea that high electromotive force generated by powerful induction coils was necessary to force the current through the cable and create a signal. The result was disastrous and the

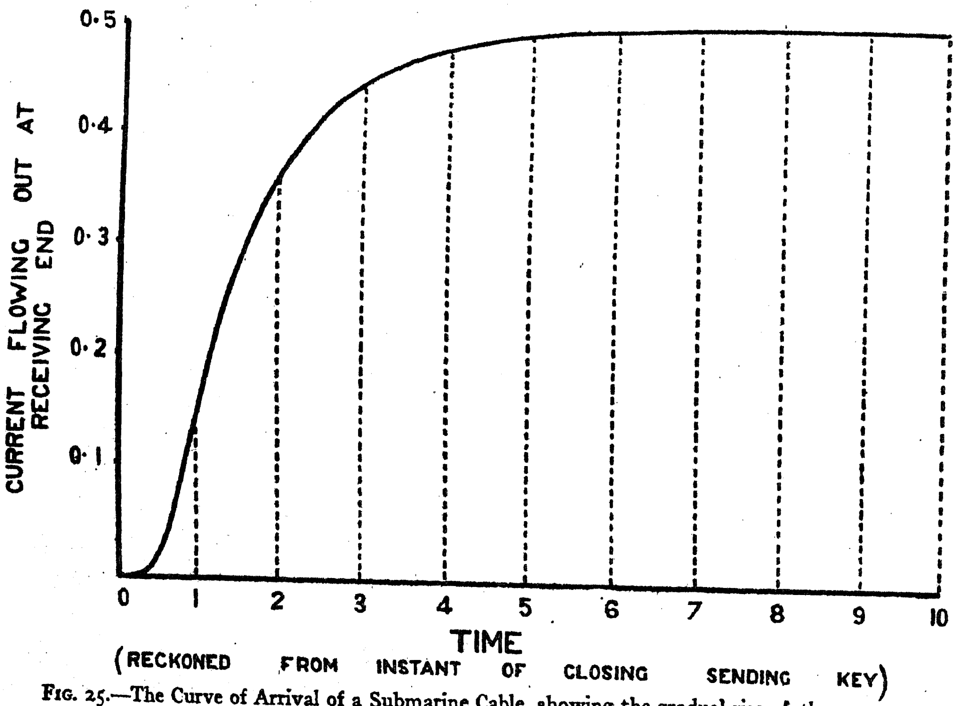


FIG. 25.—The Curve of Arrival of a Submarine Cable, showing the gradual rise of the current at the receiving end after certain intervals of time.

gutta-percha insulation was permanently injured. Hence, after a week or so of this severe treatment the cable succumbed, and after two months no further signals could be obtained.* Before that time Thomson, guided by a correct theory, had foreseen that the only safe method of signalling was to increase the sensitiveness of the receiving instrument

* The author possesses a sample of this 1858 Atlantic cable, which was given to him by Sir Charles Bright (see Plate 14, page 27).

and operate the cable with feeble electromotive forces. Hence he had already invented his beautiful mirror galvanometer.

In this instrument the "needle" consists of a few fragments of magnetised steel watch-spring cemented to the back of a small circular silvered glass mirror about $\frac{3}{8}$ inch in diameter. This is suspended within a coil of insulated wire of very many turns by a short fibre of cocoon silk. The little magnet is constrained to remain in the plane of the winding of the wire by the action of an external control magnet. A ray of light from a lamp falls upon the mirror and this latter reflects it and forms a spot

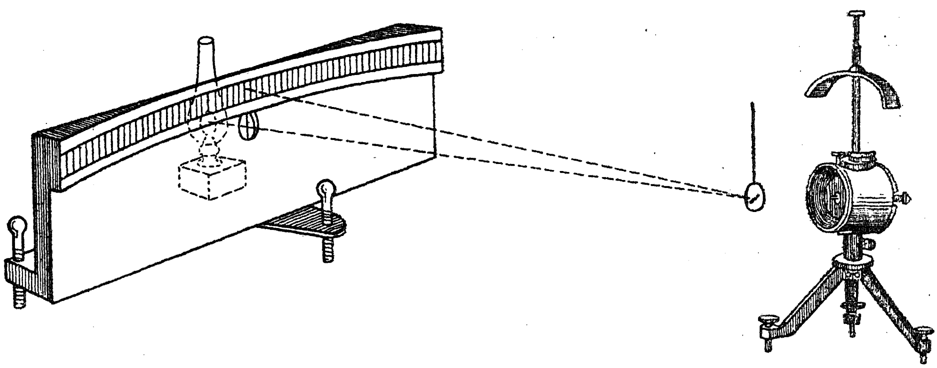


FIG. 26.—Kelvin (Thomson) Mirror Galvanometer for receiving signals through short submarine cables.

of light upon a screen 1 yard away. If the needle is deflected by a very weak current passing through the coil the spot of light on the screen is deflected also; nay, more, because the angle through which the ray of light turns is, by well-known optical laws, twice the angle through which the mirror turns (see Fig. 26). Moreover, feeble currents of short duration deflect the spot of light to one side and currents in the opposite direction reverse the deflection. Hence, if placed at the receiving end of the cable the telegraph clerk can read off the *dots* and *dashes* being made at the transmitting end by the depressions of the sending key.

It is said that Lord Kelvin was led to the invention of this admirable instrument by noting the reflection of sunlight from his eyeglass. He was accustomed to wear a monocle or single eyeglass attached to a silk cord. Holding this one day in his hand the eyeglass reflected a ray of sunlight

on to the wall and the motions of this spot of light greatly magnified the slight vibrations of the suspended eyeglass. Years afterwards, James Clerk Maxwell, to whose great scientific work we shall later on refer, wrote some playful verses in the style of Tennyson's "Blow, Bugle, Blow" on the Thomson mirror galvanometer, the first verse of which is :—

"The lamplight falls on blackened walls,
And streams through narrow perforations;
The long beam trails o'er pasteboard scales
With slow decaying oscillations.
Flow, current, flow, set the quick light-spot flying.
Flow, current, answer, light-spot, flashing, quivering, dying."

The instrument supplied not only a necessity for cable working, but, as the advertisements say, "a long felt want" in every physical laboratory as an instrument of precision for electrical measurements. Lord Kelvin's inventive power in respect of new instrument designing was absolutely limitless, and by it he left his mark in every subject to which his thought was turned.

This mirror galvanometer was employed on board ship to test the 1858 Atlantic cable during laying, and even after the reckless application of the high electromotive force had seriously injured the cable, signals and messages could be got through it by "mirror galvanometer," when to all other receivers the cable was dumb.

After this failure no further attempt was made until 1865, when capital was secured and a new and more substantial cable manufactured. The ship selected for the work of laying was the S.S. *Great Eastern*,* an iron paddle and screw steam vessel of 32,150 tons displacement, which had been designed by the eminent engineer, Isambard Kingdom Brunel, and built by Mr. Scott Russell. The cable was stored in three circular tanks built into the vessel. In spite of all the care and preparations, the attempt to lay the cable in 1865 was defeated by repeated breakage. Again a new cable was made, and in 1866, not only was this laid success-

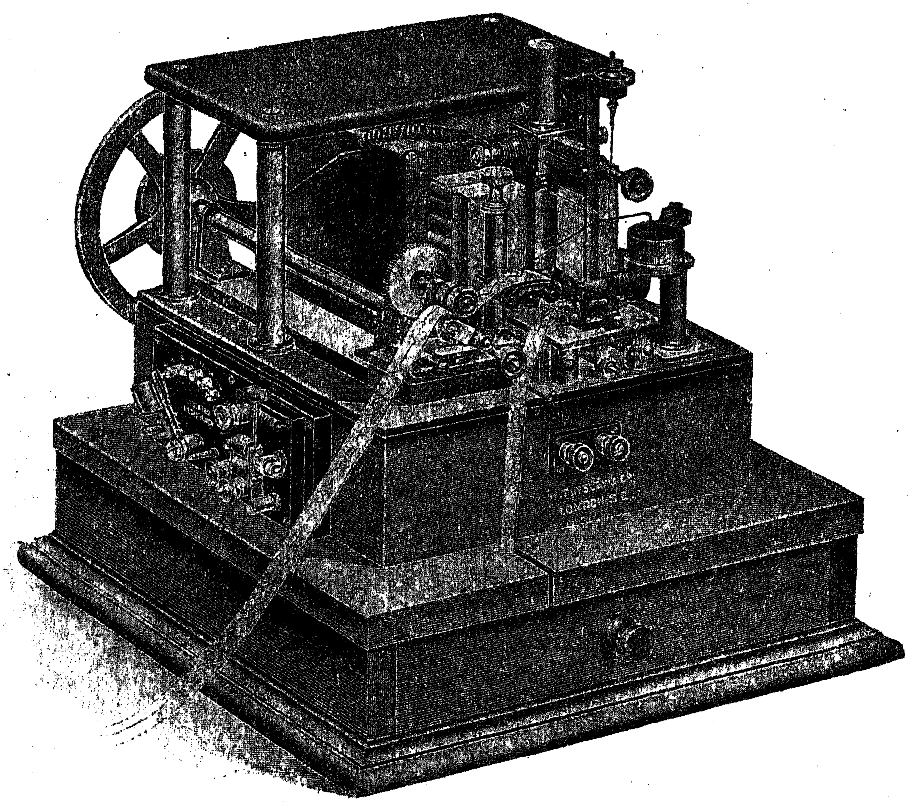
* The S.S. *Great Eastern* was built at Millwall on the Thames. Owing to her great length (680 feet) her designer built her parallel to the river, intending to launch her sideways, and not end-on as usual. The launching was several times attempted in vain, but she was got afloat on January 31st, 1858. One of the author's earliest recollections as a boy was that of being taken an excursion down the River Thames and seeing this gigantic vessel on the stocks a few months before the first attempt at launching her.

fully, but after thirty attempts the 1865 cable was grappled, raised from a depth of two miles in the ocean, spliced to a fresh length and the laying completed. Thus, two complete Atlantic cables were provided and a vast store of experience accumulated by the long record of failure and final success.

To exhibit the extraordinary sensitiveness of the mirror galvanometer, Mr. Latimer Clark on one occasion had the 1865 and 1866 Atlantic cables joined at Newfoundland, so as to make one complete loop of cable nearly 4,000 miles in length. Placing in a lady's silver thimble a little dilute acid, he immersed in it a small rod of zinc, and thus made a tiny voltaic cell. With this single cell he sent signals through the two conjoined Atlantic cables and received them on the Thomson mirror galvanometer. At a little later date, in 1867, Lord Kelvin, then Sir William Thomson, invented a still more useful instrument for cable work, called the syphon recorder. His inventive genius in designing new forms of electrical instrument was almost boundless, and every one of his productions embodied the most perfect application of correct scientific principles. The syphon recorder (see Fig. 27), consists of a powerful electromagnet, or sometimes a strong permanent steel magnet, placed with poles upwards. To these are fixed soft iron pole pieces with a narrow gap between them. In this gap is suspended a narrow rectangular coil of very fine silk-covered copper wire. The coil is suspended with its plane parallel to the field of the magnet. When a feeble electric current passes through the coil it turns itself right or left, according to the direction of the current, as far as the bifilar controlling suspension allows. To this coil is attached a very fine glass tube, bent as shown in Fig. 27. One end of this dips into some ink in a well and the ink is drawn along the tube by capillary action. The other end of this syphon rests on a strip of paper, which is moved under the syphon by clockwork. If the coil is at rest the syphon traces on the paper a straight line. If the coil deflects for a moment, to the right or left, the syphon makes a notch on the line.

The telegraphic dot is represented by a sudden brief movement of the coil to one side and the dash by an equally brief movement in the opposite direction. Hence, if dots and dashes are sent, forming words, the line traced by the syphon is a wavy line (see Fig. 28). To reduce

the friction and make the coil deflect with a very weak current, the end of the syphon is supported by a silk thread attached to the vibrating armature of an electromagnet, which operates like an electric bell. This continually lifts the tip of the pen off the paper and then lets it down



[*By permission of Mr. H. Tinsley.*

Fig. 27.—A modern form of Syphon Recorder (Tinsley) for recording on paper tape the signals coming through a long submarine telegraph cable.

again, so that the line is formed of a close sequence of minute ink spots. The lifting of the pen point, however, relieves the friction, and a smaller current then operates the instrument. This syphon recorder is a most beautiful and ingenious instrument, and is employed on all long submarine cables for receiving the signals.

A long cable is, however, somewhat sluggish in responding at the receiving end to signals made at the transmitting end, and hence, with increasing length, the signals become less well defined, as described in Chapter I.

We must next consider the state of one or two other branches of electrotechnics which had begun to germinate before 1870.

Unquestionably, the greatest of Faraday's electrical discoveries was that of magneto-electric induction.

Fully acquainted with the fact that a static electric charge on one conductor induces or calls forth an electric charge of opposite sign on all neighbouring conductors, Faraday had asked himself the question, prior to 1825, whether an electric current in one wire could not induce a second current in a nearby circuit. His first experiments were not successful, but in 1831 he renewed his attack on the problem. On an iron ring he wound two cotton-covered copper wires and through one of

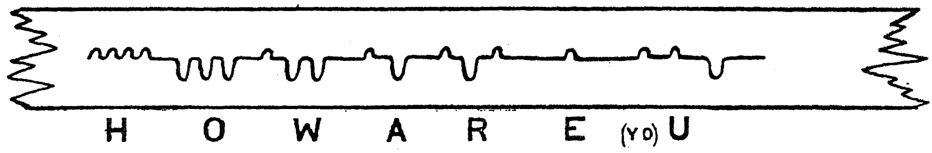


FIG. 28.—Sample of Paper Tape with Signals made by the Syphon Recorder on it.

these he passed an electric current from a voltaic battery. The other wire he connected to a galvanometer. He found that at the instant when the current started or stopped in one wire, there was a brief transitory current in the other wire, called an induced current. He then proceeded to make a modification of the experiment. Knowing that a current in a wire, wound spiral fashion on an iron bar, magnetises it, he saw that the above iron ring must be magnetised by the primary current, and he inferred that the brief secondary current was due to the magnetisation or demagnetisation of this iron core. He therefore wound on a short iron bar a coil of insulated wire and connected the ends of it to his galvanometer. He found that when this bar was placed on the poles of a steel permanent magnet an induced electric current was created in the wire wound on the bar. He also noted that when the bar was pulled off again there was also a brief secondary current, but in the opposite direction to the current when the bar approached the magnet poles (see Plate 16, page 33).

He then clearly recognised that this induced current must be due to the insertion or removal of lines of magnetic force from the secondary coil and, with wonderful insight, he inferred that if a copper wire connected to a galvanometer were simply moved between the poles of a magnet and across the lines of magnetic force, so as to "cut" them, an electric current would be induced in the wire. He found it to be even as he anticipated.

Finally, by a great stroke of genius, he made a further forecast, viz., that if a copper disk, having one spring contact pressing against its axis and another against the perimeter, the two being connected to a galvanometer, was rotated quickly in a magnetic field, the lines of force of which were perpendicular to the plane of the disk, it would create a steady electric current flowing through the galvanometer as long as the disk was rotated (see Plate 16, page 33). Experiment fully verified this anticipation. Faraday thus made the greatest of all his discoveries, viz., that an electric current could be generated in a wire or conductor merely by moving it in a strong magnetic field near the poles of a magnet, so as to cut across the lines of magnetic force. Tyndall says of this feat that it was the Mont Blanc of all Faraday's achievements. He always worked at high elevations, but higher than this he never subsequently attained. Thus was born into the world the first rudimentary dynamo or machine for generating electric currents merely by the mechanical motion of a copper conductor in a magnetic field. In ten days of experimental work in the autumn of 1831 Faraday explored so thoroughly, in the laboratories of the Royal Institution of Great Britain, the new phenomena he thus brought to light, that no one has since been able to add anything to his work in the discovery of fundamental facts. Faraday, however, applied, and rightly so, his great genius to the advancement of scientific knowledge, and he left it to others to work out the logical consequences of his discoveries in technical applications.

Almost immediately inventors began to make such applications of magneto-electricity. H. Pixii, in 1831, produced a machine for generating an alternating electric current by the rotation of a permanent magnet in front of certain bobbins of wire called the armature. A year later he made an addition to the machine called a *commutator*, which enabled it to

provide a current of electricity always flowing in one direction in its external circuit, now called a direct current (D.C.) (Fig. 29).

In 1833, J. Saxton, and in 1835, E. M. Clarke, followed with the invention of magneto-electric machines which gave a direct current by

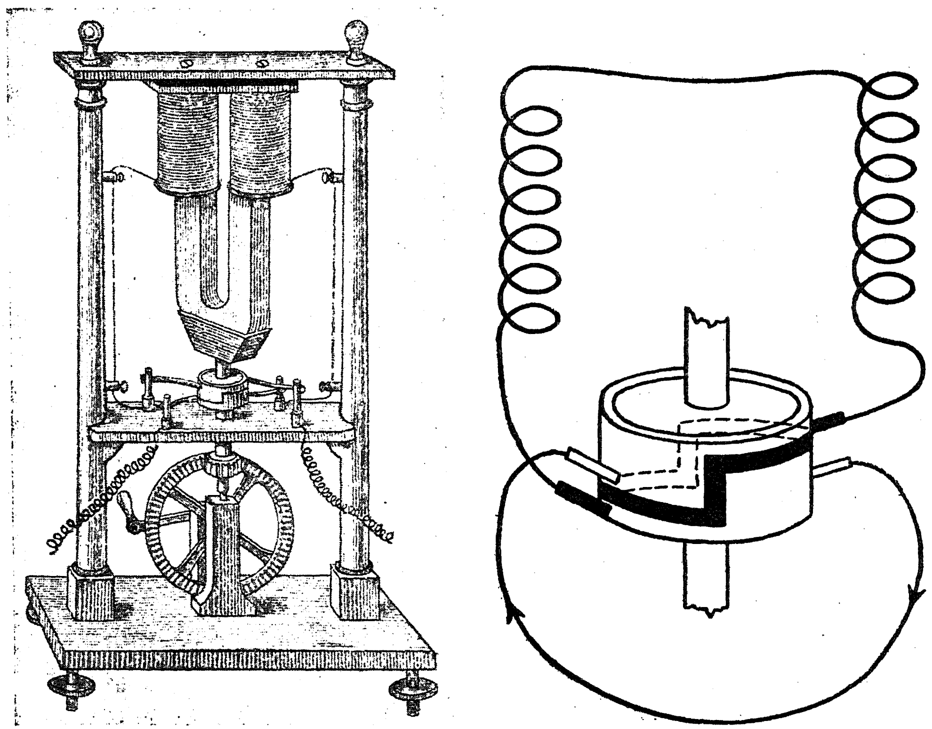


FIG. 29.—Pixii's Magneto-machine, 1831, for generating an electric current by the rotation of a steel horse-shoe magnet with its poles nearly touching the iron core of a fixed electromagnet. The commutator is shown in the diagram on the right.

the rotation of coils of wire called the armature, in proximity to the poles of a fixed permanent magnet.

The action of this simplest form of dynamo is, then, as follows: Let there be a horse-shoe shaped permanent magnet, and let a horse-shoe shaped piece of soft iron (see Plate 16, page 33), the legs of which are wound over with coils of insulated copper wire, be attached to an axis so as to rotate with the coils near to the poles of the magnet.

Then it is easily seen that when the soft iron armature has its ends in contiguity to the magnet poles, lines of magnetic force will pass through the wire windings. If, now, the horse-shoe shaped armature core is given half a turn the lines of magnetic force will pass through the wire windings in the reverse direction. If, then, the armature is continually rotated at each half turn, an induced electric current is created in the wire windings, which flows first one way and then in the reverse through the wire if the external ends are joined. Such an arrangement is called an alternator or alternating-current machine.

To convert it into a direct-current machine we have to add to it a commutator. In its simplest form this consists of a cylinder of wood or ebonite attached to the axis of rotation, on it are fixed two curved metal plates which each occupy somewhat less than half the circumference of the cylinder. To these plates are soldered the ends of the wire wound on the armature.* Against these curved plates two springs or brushes press. It will be seen that at each half turn the electric contact between plates and brushes is changed in such fashion that although the current in the wire of the armature is an alternating current—that is, flows first one way and then the other—the current in the external circuit is always in one direction. This device is called a commutator, and a direct-current machine is therefore distinguished from an alternator by having a commutator (see Fig. 29).

A large compound magneto machine giving an alternating current was invented in 1849 by Nollet, and a similar type of machine by Holmes was later on used in the South Foreland Lighthouse to create current for an electric arc lighthouse lamp.

In 1856 Dr. Werner von Siemens invented the shuttle-wound armature, consisting of a cylinder of iron with two deep longitudinal grooves, in which insulated wire was wound, the ends of the wire being attached to the two curved plates of a simple commutator.

* The word "armature" originally meant a knight's armour. When it was found that the attractive power of a loadstone was increased by putting on its polar ends iron caps, these latter were called the magnet's armature. Then when steel permanent magnets were made, the term "armature" was applied to the soft iron bars or blocks used to join the poles and complete the magnetic circuit. It is now applied to the revolving or stationary coils of a dynamo in which the current is induced by the field magnets.

This armature was caused to revolve in the interpolar space of a powerful magnet provided with pole pieces curved so as to embrace closely, without touching, the shuttle-wound armature.

In 1860, Dr. Antonio Pacinotti, of Florence, devised a new type of armature wound on an iron ring. This same type was later on re-invented by a Belgian electrician, Z. T. Gramme, and is now called a "Gramme ring armature." These forms of armature are more particularly described in Chapter II.

An important improvement was introduced soon after 1850, viz., the employment of electromagnets instead of permanent magnets to create the field in which the armature revolves. H. Wilde invented a machine in which a small magneto machine having a permanent steel field magnet produced the electric current required to energise the field electromagnets of a larger machine.

A more important discovery was made about 1867 by Wilde, Siemens and Wheatstone, viz., that such a machine could become self-exciting if part or the whole of the current given out by the armature is passed through the coil windings of the field electromagnets. When the field magnets are electromagnets there is always a small amount of residual magnetism in them which is sufficient to create a small electromotive force in the armature coils when these are rotated. If the ends of the windings on the field magnets are connected to the brushes resting on the commutator, then this small electromotive force (E.M.F.) will create a current in the field magnet windings, which in turn will exalt the magnetic field and therefore the armature E.M.F. Hence, by mutual reaction the field and the armature E.M.F. increase one another up to a certain limit, and their current can be drawn off from the armature into an external circuit. Such a mode of connecting the field magnet windings forms a so-called *shunt wound dynamo*. If, on the other hand, the field magnet windings are in series with the armature the whole armature current goes through them. This is called *series winding* (see Fig. 30). It is obvious that a shunt wound dynamo can generate a terminal E.M.F. at the brushes even if there is no complete external circuit. On the other hand, a series machine cannot generate a current or an electromotive force unless the armature and field circuits are completed by an external circuit.

Although, therefore, prior to 1870 we can say that the dynamo machine had been invented, yet with the exception of a certain small amount of electric arc lighting and some employment in supplying electric current for electro-plating there was no extensive technical use of it.

Electrical engineering, before 1870, was practically confined to telegraphic engineering, land and submarine. The only electro-technical society

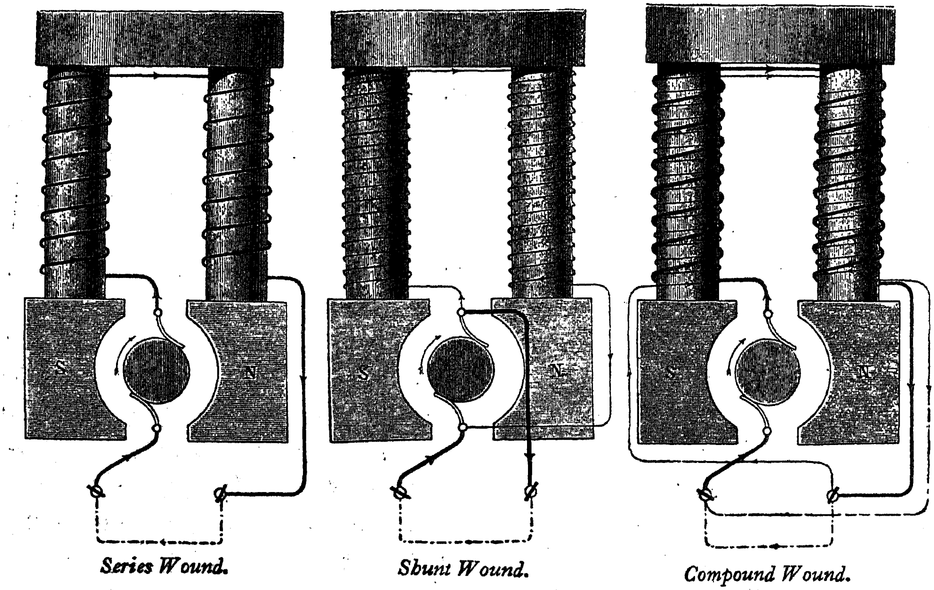


Fig. 30.—Various Methods of Winding and Connecting up the Field Electromagnets of a Dynamo. The central disk represents the end-on view of the armature.

of that date was called *The Society of Telegraph Engineers and Electricians*, and its discussions comprised the theory and practice of this art alone. Electro-plating had become a considerable industry, and certain attempts had been made to devise electric incandescent lamps for domestic electric lighting with but little success. There was no public distribution of electric currents, no private or street electric lighting, no electrical transmission of power, no telephones and no electrometallurgy or electric heating.

With the year 1870 a new era was ushered in, in which the wonder-

working electric current generated by dynamo machines became an important factor in human life. The detailed story of its applications will occupy succeeding chapters and record remarkable achievements, with many of which the author has been closely connected during the past fifty eventful years.

CHAPTER I

TELEGRAPHS AND TELEPHONES FROM 1870 TO 1920

As soon as the transfer of the business of telegraphy from the British Telegraph companies to the State had taken place in 1870 the Telegraph Department of the General Post Office began to augment the public facilities for telegraphy by installing apparatus in post offices in every town and village, and also considered inventions for increasing the speed of transmission of press and private messages.

Attention was first directed to the improvement of automatic apparatus on the Wheatstone system. In the case of ordinary hand signalled messages the speed with which words can be transmitted per minute depends upon the skill of the manipulator of the transmitting key and on the rate at which the receiving clerk can read the signals by eye or ear. This does not generally exceed thirty five-letter words or 150 letters per minute and it taxes endurance to keep this up for long together.

In the automatic system the message to be transmitted is first translated into a set of signs represented by holes punched in a strip of paper tape. In the case of a long message the various paragraphs can be so punched simultaneously by different operators on separate tapes. These tapes are then fed in proper order through a machine called a transmitter, which sends corresponding electric currents into the line and they are recorded at the receiving end by a Morse printer. By such methods speeds of 200 to 400 words per minute can be sent and received.

Turning then to details, the first stage is the preparation of the paper tape. This is provided in long, flat rolls, consisting of thin, tough, white paper half an inch wide.

In it are punched three rows of holes. One row of equidistant small holes in the centre is employed for feeding the paper forward through the transmitter. On either side of this are punched larger holes. A telegraphic *dot* is represented by two holes in line with each other across

PLATE I.

[By permission of the India Rubber, Gutta Percha, etc., Co., Ltd.

A Perforator for punching Wheatstone Paper Tape by hand. The paper strip is fed through the machine, and the operator punches the pair of holes required for a *dash* ·. or the pair required for a dot : by striking the right-hand or left-hand circular button with a wooden hand plug. The centre button makes the space.

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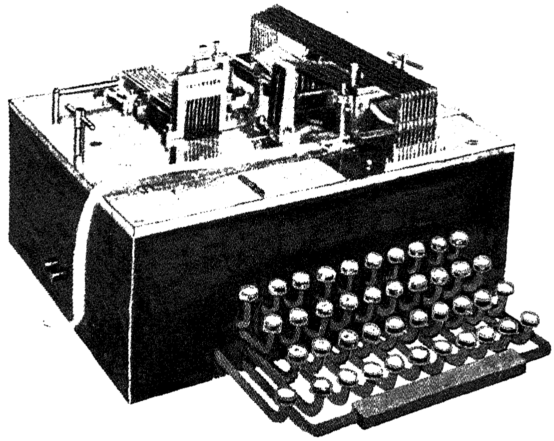
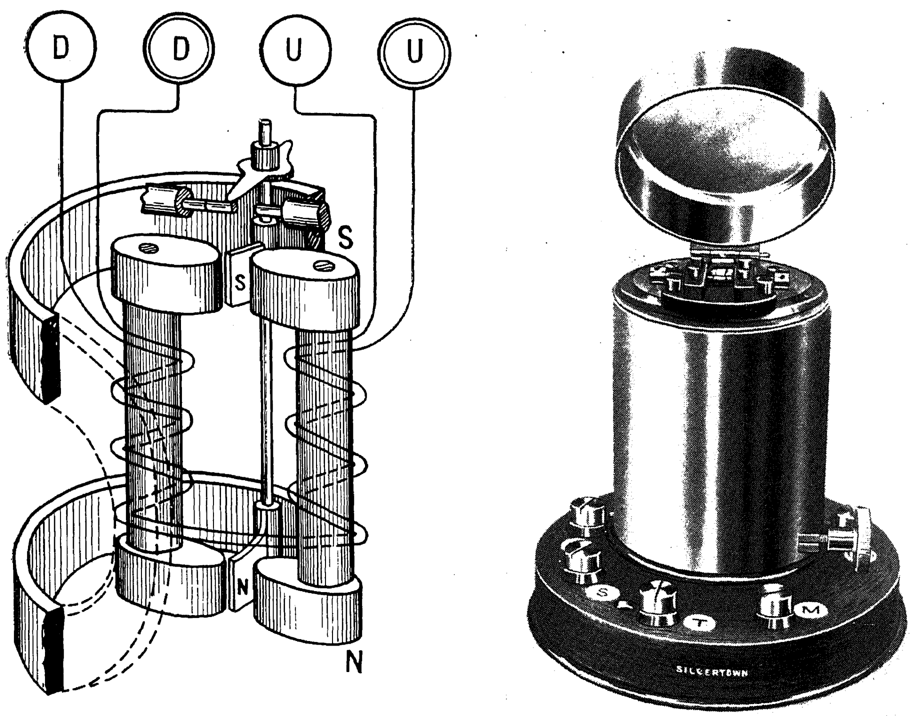


A Gell Keyboard Perforator for punching Wheatstone Tape. The operator touches the keys in front, each of which is marked with a letter or number, as in a typewriter. The depression of this key makes the entire group of holes in the tape which correspond to that letter.



[*By permission of the India Rubber, Gutta Percha, etc., Co., Ltd.*

A Double-current Relay, differentially wound. The external appearance is shown in the right-hand figure, and the mechanism in the interior in the left-hand figure. (See page 52.)

[*To face page* 51.

the tape and on either side of the central holes. A *dash* is represented by two holes, one in advance of the other (see Fig. 1). Thus, the word OF would be punched out as in Fig. 1, where the first three slanting pairs of holes represent O = —— —— ——, the second group of four holes denotes the letter F = – – —— –. This punching is conducted either by punches worked by hand or by special machines actuated by compressed air or electromagnets, the human operator merely pressing lightly one or other of three piano-like keys to form the holes corresponding to a space, a dot or a dash (see Plate 1).

Of late years ingenious machines like typewriters have been invented, such as the Gell and the Creed perforators, each key of which stands for a letter and, when depressed, forms at once in the paper tape the entire group of holes standing for that letter of the alphabet. These typewriter perforators can be worked by any one who can use an ordinary typewriter, and with the same speed (see Plate 2). The punching power in the case of these last instruments is supplied by electromagnets, and the touch of the operator on the key merely releases that power.

We have next to describe the transmitter and, as preliminary to this, we must briefly explain the nature of a double-current relay.

In the original Morse system the signals are sent by transmitting into the line for a short or longer period an electric current which flows always in the same direction. The current actuates at the far end an electromagnet, and this attracts or releases an armature. This is called *single-current* working. In *double-current* working the letter signals are made by reversing the direction of a current which is always flowing in one direction. Hence, the dots and dashes are made by a current called the *marking current*, which is in the opposite

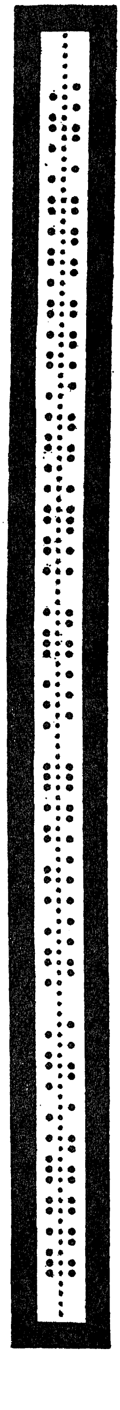


FIG. 1.—Sample of the Punched Tape used in the Wheatstone Automatic System of High-speed Telegraphy. The centre line of small holes is for moving the paper forward. The larger holes on either side are the signal holes. A *dot* is represented by two side holes immediately over each other, and a *dash* by two holes, one a little in advance of the other.

direction to that which flows during the intervals, called the *spacing current*.

In a double-current relay there are two vertical bar electromagnets (see Plate 2), and the wire so wound on them that a current flowing in one direction from terminal D to U makes the two upper ends, respectively, North and South. The reversal of the current reverses the magnetic polarity of both upper poles. Between the upper and lower poles are

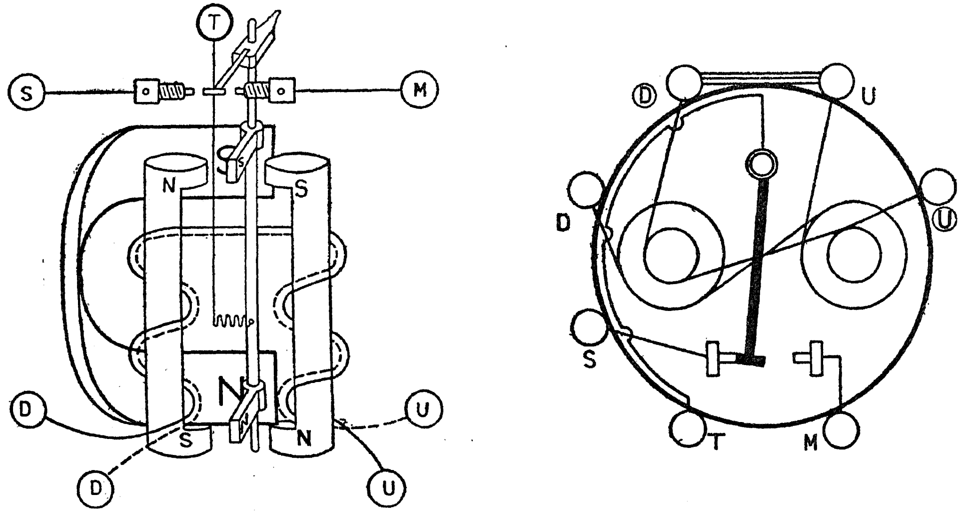


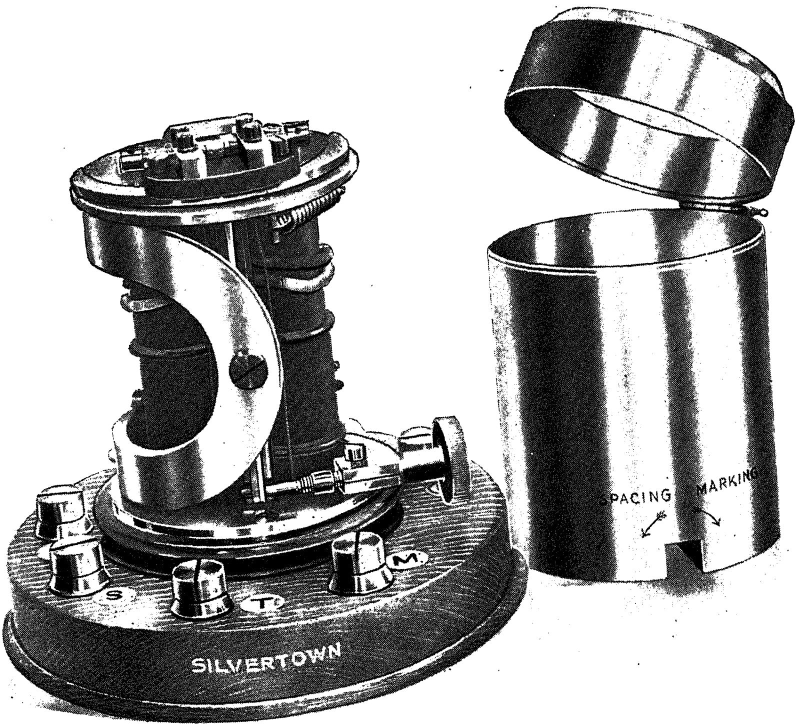
Fig. 2.—Arrangement of a Double-current Relay. The left-hand diagram shows an elevation and the right a plan of the magnets and connections. N and S are the poles of the curved steel polarising magnet. N and S are the poles of the electromagnets, and N S the soft iron tongues, and T, M, S the contacts. The electromagnets are wound with double wires—one shown by a dotted line, and one by a firm line—ending respectively in terminal screws D, D and U, U. This is called a differential winding, and is employed in duplex working, as explained in the introductory chapter.

two soft iron tongues attached to a vertical, freely-rotating steel spindle, which also carries a third tongue of non-magnetic material tipped with platinum. This last tongue can move within limits, so as to touch one or other of two platinum-tipped screws on either side of it (see Fig. 2).

The two soft iron tongues N, S attached to the vertical spindle, are kept permanently magnetised, North and South, respectively, by a curved horse-shoe permanent steel magnet.

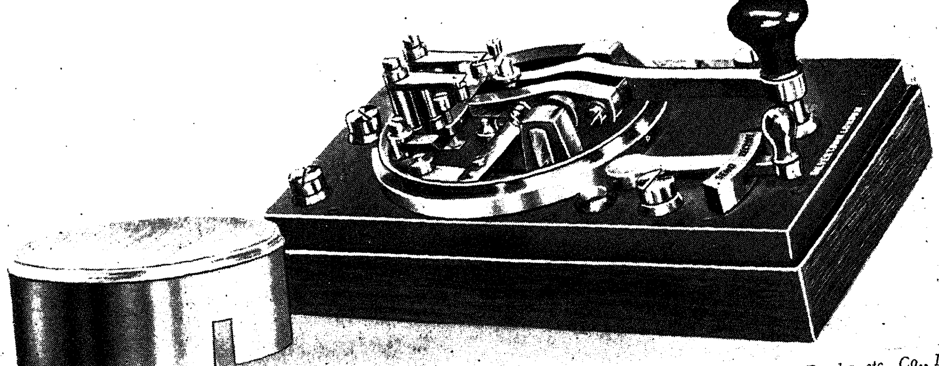
The last magnet has its poles N, S near to the ends of the soft iron tongues.

PLATE 3.



[By permission of the India Rubber, Gutta Percha, etc., Co., Ltd.

Double-current Relay with outer case removed, showing part of the Curved Polarising Permanent Steel Magnet and also the Straight Bar Electromagnets.



[By permission of the India Rubber, Gutta Percha, etc., Co., Ltd.

A Double-current Telegraph Key. The large black knob on the end of a lever is the sending key. (See page 54.)

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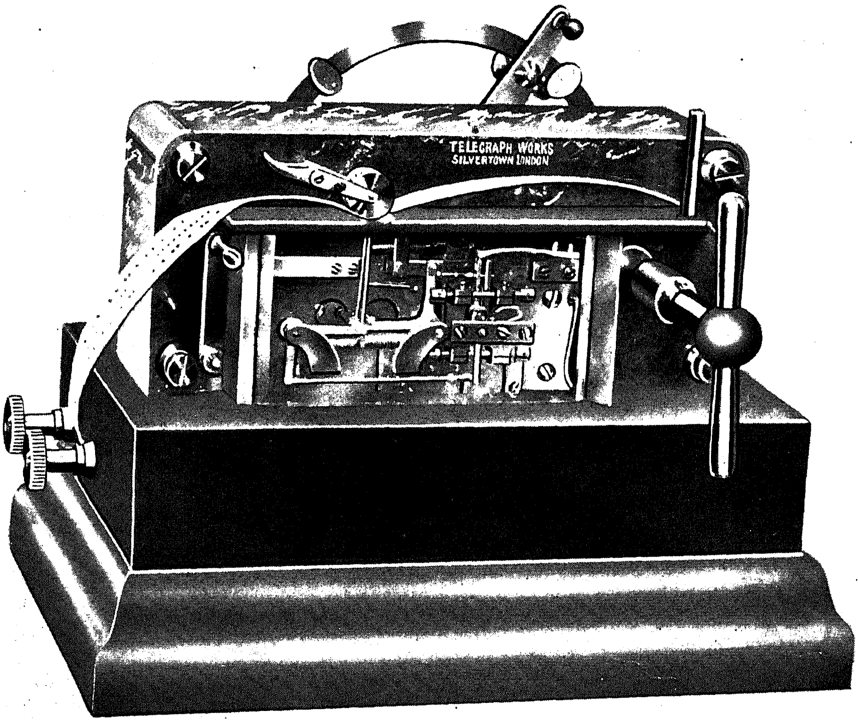
PLATE 4.



[*By permission of the India Rubber, Gutta Percha, etc., Co., Ltd.*

The Wheatstone Automatic Transmitter. The mechanism is driven by clockwork wound up by the T-handle. (See page 54.)

[*To face page* 53.

It will be evident that when the current is sent through the coils of the electromagnet in one direction it pulls over the iron tongues to one side and, therefore, causes the upper tongue to make contact with one or other of the platinum-tipped screws. These screws are connected to two terminals, marked M and S, and the upper tongue to a terminal marked T.

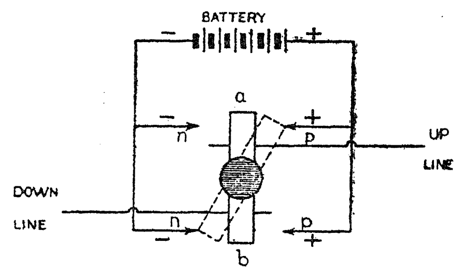


FIG. 3.—Diagram illustrating the Connection of a Double-current or Reversing Telegraph Key.

The current through the electromagnet, therefore, causes the upper tongue to move over, so as to connect electrically the terminals T and S or T and M, according to the direction of the current (see Fig. 2).

The general appearance of the relay with outer case removed is shown in Plate 3, upper diagram.

It is necessary then to describe a sending appliance to correspond,

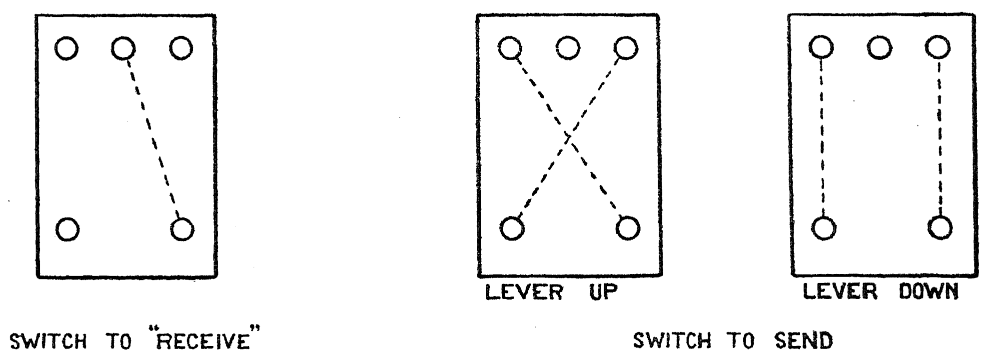


FIG. 4.—A Double-current Telegraph Key. The two outside screws at the back of the board are connected to the terminals of a battery, and the middle back screw to a receiving instrument. Two front contacts are connected to the up and down lines, or to line and earth respectively. When the key is pressed it puts the battery poles respectively to the up and down line terminals, as shown by the dotted lines in the right-hand diagram. When this key is not pressed the battery is sending a reversed current into the lines. This latter current is the spacing current, and the direct current, when key is pressed, is the marking current. When signals are not being sent the little side lever is switched over and puts the line to the receiving instrument.

called a double-current key. In principle it is as follows. Let there be a voltaic battery, B (see Fig. 3), which has its positive and negative pole, connected respectively to two pairs of terminal pins marked in the

diagram + and —. Let a lever, consisting of two metal rods, separated by a piece of insulating material on the centre, work round a pivot, so as to oscillate to and fro, and connect the ends of a line and an earth plate to opposite poles of the battery + or —, according to the direction or inclination of the divided lever. This will send into the line a positive or a negative current, depending on the side towards which the divided lever is inclined. Such an arrangement is called a double-current key. The

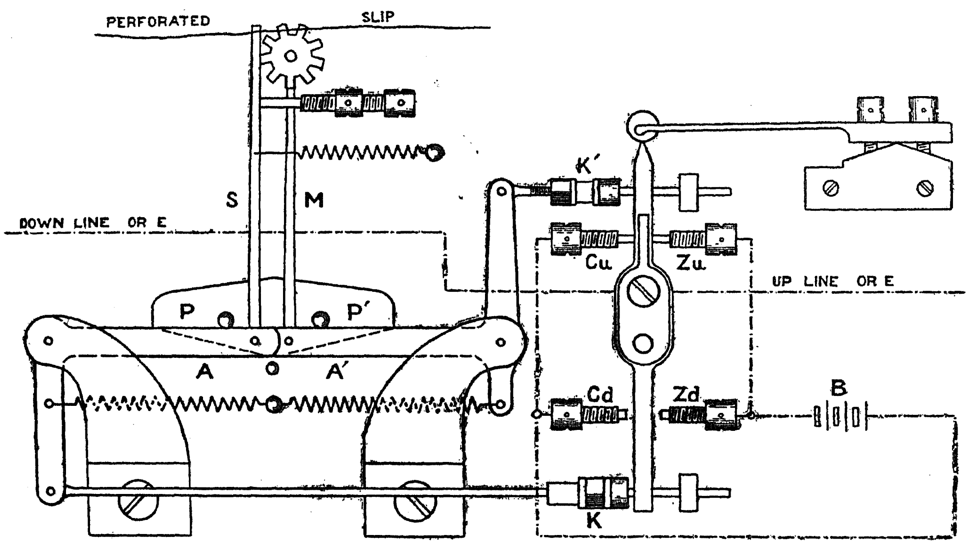


Fig. 5.—Diagram explaining the Action of the Transmitter in the Wheatstone Automatic System.

real double-current key is a little more complicated, but its appearance and mode of working is shown in Fig. 4 and Plate 3, and associated description.

We can now proceed to describe the essential mechanism of a Wheatstone automatic transmitter, which is merely a double-current key, the lever of which is moved by clockwork or an electric motor and the movements controlled by punched paper strip, made as above described.

In this instrument the punched paper strip is carried forward by the teeth of a little revolving star wheel, which engage in the equi-spaced perforations in the centre of the paper strip (see Fig. 5). Below the paper are two vertical steel pins S, M, which can move upwards through the

:eral or side holes in the paper when these holes come over the tops of ≥ pins. These pins move up through the holes almost simultaneously ʟen a pair of aligned *dot* holes in the paper come over them, but with :ertain interval of time when an inclined pair of *dash* holes pass.

These pins rest on two bent levers, A A′ (see Fig. 5), which are rapidly ›ved up and down by transverse pins, P P′, on a rocking lever which :aused to rock or oscillate with extreme rapidity. If a side hole in the ›ving paper strip comes over the top of a vertical pin, the latter will be ·ved upwards, when the pin P or P′ on the rocking lever rises. On king at Fig. 5, which shows the mechanism diagrammatically, it will seen that there are four little screws marked *Cu*, *Cd*, *Zu*, *Zd*, which respectively in connection with the poles of a battery B. Between m moves the divided lever, the sections of which are connected to the and down lines respectively. This lever is moved by two rods K, K′ ached to the cranked levers A A′, and these rods have nuts on them ich cause the movements of the cranked levers to be communicated the divided lever.

Consider the motions as the tape passes along over the tops of the tical pins. If no side perforations pass, neither of the vertical pins move upwards and, as the rocking lever moves to and fro, it only ws the horizontal rods through the holes in the divided lever without placing the latter, which, we shall suppose, lies over in a direction to d out spacing current into the line. If a pair of *dot* holes in the tape ne above the pins, then the inner ends of the crank levers A A′ can in quick succession, and the result is to pull over the divided lever :he other side and then push it back again. This sends out into the a brief marking current which records a *dot* signal. If, however, a : of inclined or *dash* holes in the paper come over the top of the pins, same action occurs, but with a delay which permits a marking current onger duration to pass, and records, therefore, a *dash* signal.

The rocking lever is moved by clockwork driven by a heavy weight lse by an electric motor.

The paper strip is saturated with olive oil to give it a smooth surface permit clean holes to be punched in it. It travels through the transter at rates varying between 7 and 80 feet per minute, and at the

highest speed can transmit 400 words per minute. A general view of the Wheatstone automatic transmitter is shown in Plate 4, page 53.

In recent types of instrument the transmitter is driven by an electric motor.

Turning, then, to the receiving instrument, we may say that it is a kind of Morse ink recorder operated by a reversed current and having the same general construction as the double current or polarised relay described above. Like the relay it contains two vertical electromagnets, and has a pair of magnetised soft iron tongue armatures attached to a vertical steel shaft, which are pulled over to one side or the other by the reversal of the current through the electromagnets. This shaft carries also a third tongue by the movement of which a little wheel kept inked on its edge is moved to or from a moving paper tape. When the armatures are pulled over by a "spacing" current sent through the electromagnet coils, the ink wheel is moved away from the paper tape. When a "marking" or reverse current is sent, the wheel is pressed against the paper for a short or longer time so as to mark on it a dot or a dash. The general arrangements of the receiver are shown in diagram (Fig. 6) and a photograph in Plate 5, page 60. The paper tape is moved through the receiver by clockwork, driven by a weight. The receiver can either be operated directly by the reversed line currents or else a double current relay can be interposed.

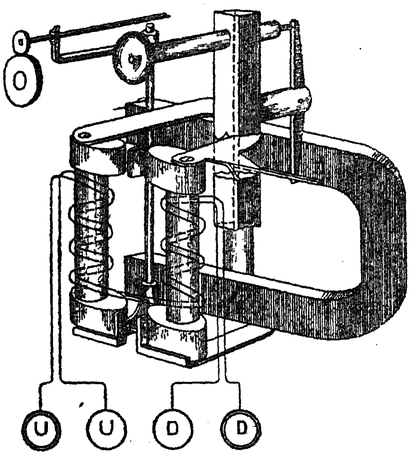


FIG. 6.—Diagram of the Mechanism of a Wheatstone Receiver for High-speed Telegraphy. The small wheel at the top left-hand corner is the marking wheel, and the larger one on which it rests is the ink-supply wheel.

One rather important addition to the relay necessary to secure high speed is the shunted condenser in series with it.

Every electric circuit, and particularly the circuits of an electromagnet, possess a property called inductance, which is analogous to inertia or mass in ordinary matter. We know that a heavy body cannot be set in motion

instantly or stopped instantly when in motion, but changes of motion require time to produce. In the same way we cannot start, stop or reverse an electric current instantly. The current requires time to grow up to its full strength or to die down again to zero.

The circuits of an electromagnet possess this property in a high degree and therefore we are unable to reverse the current through a double-current relay instantly. We therefore put in series with the relay magnet **M** a condenser **C**, which is, in fact, a kind of Leyden jar, and is constructed of sheets of paraffined paper coated on both sides with tinfoil, and

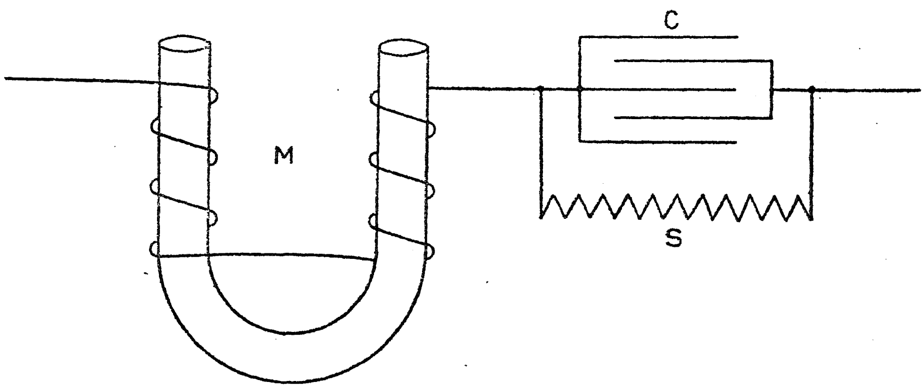


FIG. 7.—A Relay Magnet M in series with a Condenser C, shunted by a Resistance S. The effect is to nullify the inductance of the electromagnet.

we connect the two tinfoil surfaces to the ends of a suitable resistance S, which is placed in series with the magnet coils of the relay. This gives us a so-called shunted condenser. The effect of this appliance is to nullify the inductance or electric inertia of the relay and permit the current through its coils to be more rapidly reversed than would be the case without it (see Fig. 7).

In this Wheatstone automatic system the message printed on the tape of the receiver is in Morse signs, and has therefore to be translated and written out in ordinary letters for the recipient.

Mr. F. G. Creed has invented very ingenious machines operated by compressed air or electric motors which prepare a punched tape under the influence of the received electric currents, which is an exact replica of the

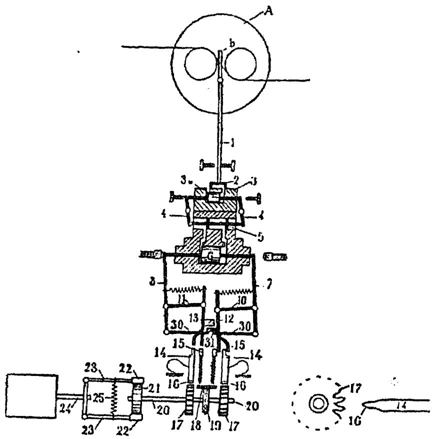


FIG. 8.—Diagram illustrating the Action of a Creed Air Receiver. The electric signals from the line are received on a relay A, and the tongue 1 of this relay operates a delicate slide valve 2, which admits compressed air to a little engine which perforates the paper tape with signal holes, as shown in Fig. 1. The tape is moved forward by an electric motor. In a more recent type of receiver an electric motor is employed as a source of power.

tape at the sending end put into the transmitter (see Plates 6 and 7, pages 61 and 62, and Fig. 8). This tape can then be used to re-transmit the message to another station. Or this tape can be passed through another ingenious machine which typewrites the message in ordinary Roman characters on a tape (see Plates 6 and 8, pages 61 and 63, and Fig. 9). This last tape can then be cut up and gummed to a telegraph form and sent out to the proper recipient. These Creed telegraph instruments are extremely complicated in structure and would require more space than can be given here for their full description. For a fuller description the reader must be referred to technical books on *Telegraphy* such as that of Mr. T. E. Herbert. It will thus be seen that the drift of

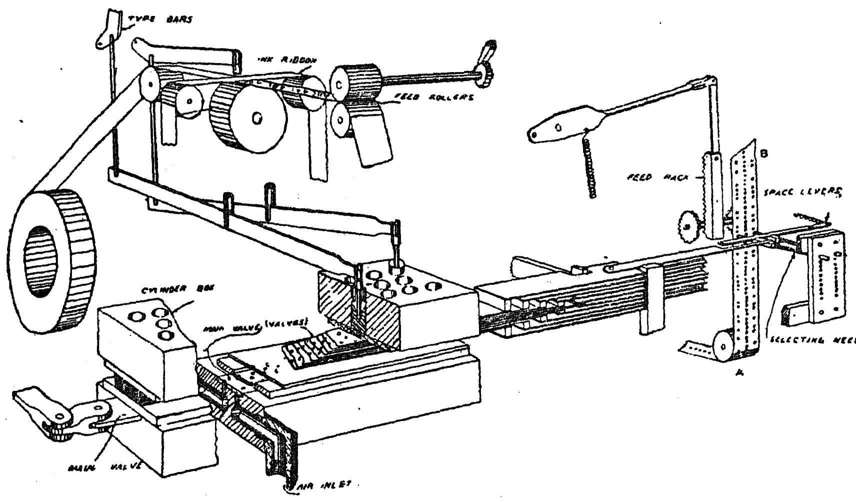


FIG. 9.—Diagram illustrating the Action of the Creed Typewriting Translator, which prepares from the Punched Tape passed through it a Facsimile printed in Roman Letters on Paper Tape.

invention has been towards devising machines which dispense with the necessity for a highly skilled telegraphic operator and substitute for

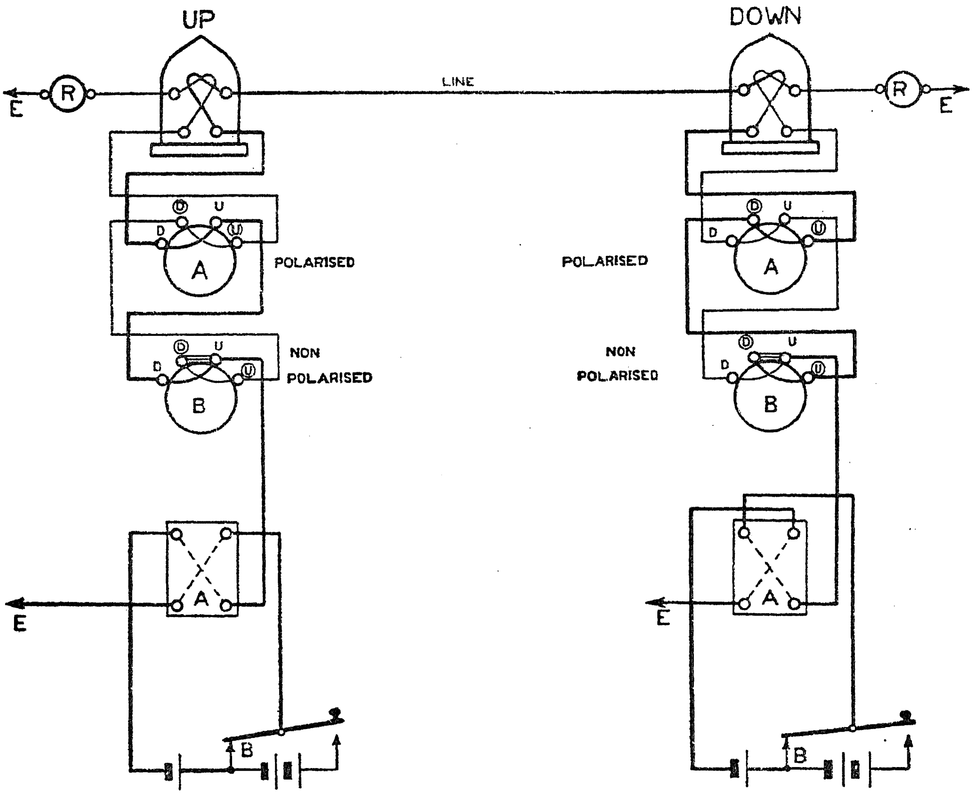


FIG. 10.—Scheme of Connections for Quadruplex Telegraphy. At each station there are two sending keys A and B. A is a double-current key and, when depressed, reverses the direction of the current flowing into the line. B is an increment key and, when depressed, increases the current into the line without altering its direction of flow. At each station there are two relays, one a non-polarised relay, which is affected only by the movements of the key B at the distant station, and the other a polarised relay affected only by the A key at the distant station. The movements of the keys do not affect the relays at the home station, because the latter are differentially wound. Hence four operators, two at each end, can send and receive at the same time.

this an ingenious machine which can be worked by any girl or boy who can manipulate an ordinary typewriter.

A very large number of Wheatstone automatic instruments are in use n the telegraph offices of the British Post Office.

Another highly important high-speed telegraphic arrangement is that known as the Quadruplex, which was first put into practical form by Mr. Edison in 1874. We have already explained in the previous chapter the principles of duplex telegraphy by which two messages are simultaneously sent in opposite directions along the same wire. In the Quadruplex four messages are sent simultaneously, two in each direction. This is achieved by the use of two signalling currents, one of which is reversed in direction to make the signal and the other current always flows in one direction, but is altered in strength from weak to strong to make the signal (see Fig. 10).

These circuits are separately duplexed. The system involves the use of two relays in each of which the electromagnets are differentially wound, that is, have two wires in each coil so that equal currents sent in opposite directions through the two coils neutralise each other and produce no magnetisation in the core. One of these relays is a polarised relay and the tongue of it is thrown over only by the reversal in direction of the current through it. The other is a non-polarised relay, and the tongue is thrown over only by the increase of the current in strength, no matter what its direction.

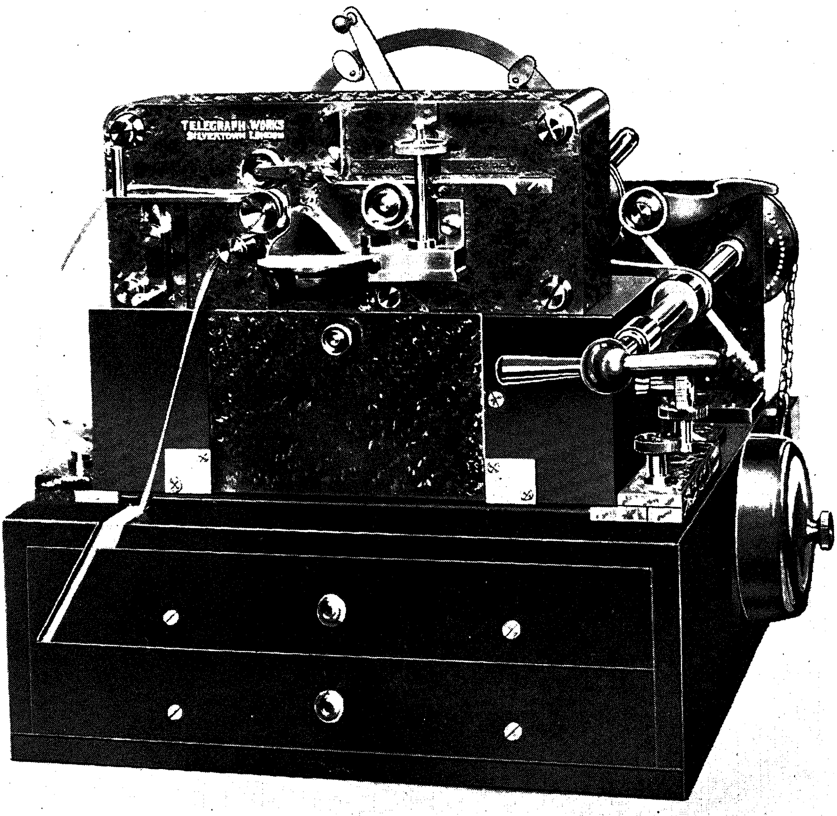
Two sending keys are employed, one of which (A) reverses the current when depressed, and the other (B) simply increases the strength by the addition of certain voltaic cells in the circuit. The reversing key and polarised relay are in the circuit called the A circuit, and the increasing key and non-polarised relay are in the B circuit.

These keys and relays are arranged in series with each other, as shown in Fig. 10.

The outgoing current is split through the two separate windings of the electromagnets of the relays at the sending station so that the currents in the two opposed windings neutralise each other's magnetising effect on the iron cores. They pass through the coils of the relay magnets at the receiving station in such directions as to create magnetism in the core. Hence, as already explained, signals can be sent in opposite directions along the line at the same time.

The A and B circuits are thus each duplexed, and this gives us a quadruplex system capable of transmitting four messages simultaneously.

PLATE 5.



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A View of the Printing Receiver used in the Wheatstone Automatic System of High-speed Telegraphy.

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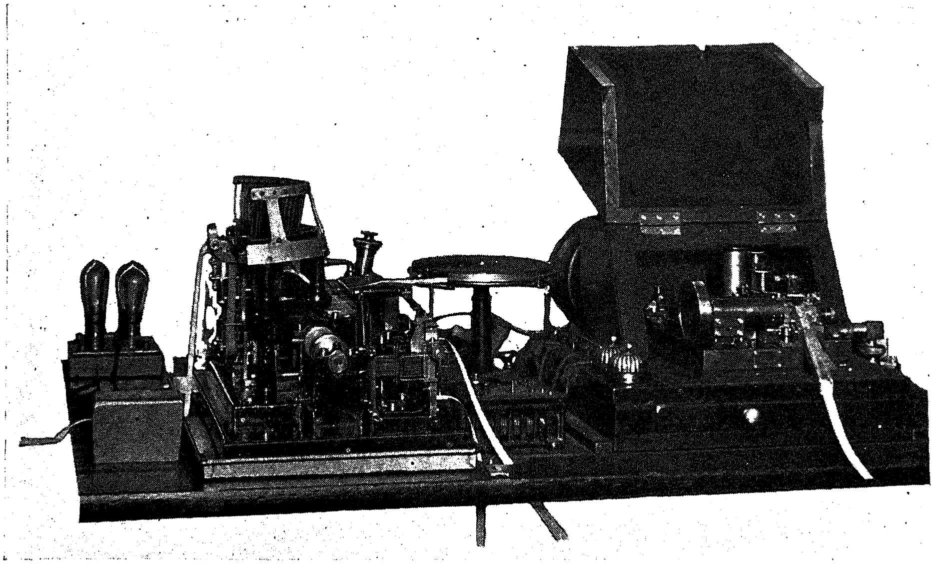
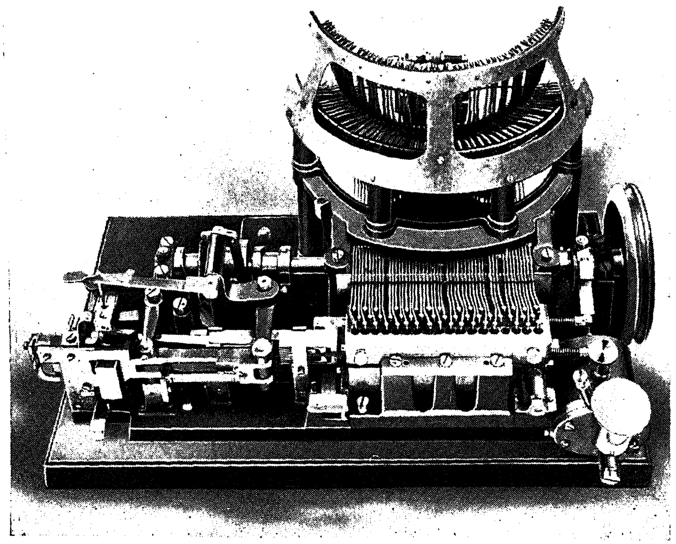
PLATE 6.



General View of the Creed Air Receiver (right-hand side) and Printer (left-hand side).



View of the Creed Compressor Printer, which prepares from punched paper tape passed through it a typewritten equivalent in ordinary printing characters. This machine is operated by compressed air.

[*To face page* 61.

There are certain difficulties in operating quadruplex in the climate of Great Britain where the earth plate resistance and line insulation is continually varying, due to rain or drought.

There are also certain technical difficulties in adjustment which call for skill. For instance, the B relay is operated by any current greater than the current which is reversed through the A relay to make the signal on the A side. When the A key reverses the current, owing to the capacity and resistance of the line the current is not reversed instantly at the far end. Also, as the A key changes over to reverse the current there is an instant when the circuit is opened. The result is to cause a stoppage of the current through the B relay, and if a B signal, say a dash, is being sent at that moment it is liable to be broken up into dots. This effect is called the "B-kick." It can be remedied by the use of certain condensers and local batteries to bridge over this fall off in the signalling current through the B relay. The Quadruplex system is still used in the British Telegraph Service, but not much on Continental circuits. It is classed as a high-speed system because each side is capable of transmitting sixty words per minute, or 120 in all, when using hand-key sending and sounder reception.

A method of increasing the speed of transmission of signals through a line, whether worked single, duplex, or quadruplex, is to divide it into sections and repeat the message by relays called *repeaters* at each junction. The result is to quicken the speed of transmission for reasons explained later on in this chapter (see upper diagram, Plate 9, page 66).

Four simultaneous messages are by no means the limit of the carrying power of a telegraph line. Methods have been invented for transmitting more than four at the same time along one line which are called multiplex methods. One of the most important of these is the Baudot system, invented about 1874–5 by J. M. E. Baudot, an employee of the French Telegraph Administration.

Baudot realised that in printing telegraphs such as the Hughes the brief currents sent out at each letter left the line so to speak idle between the signals, and he set himself to devise a method by which the line could be used in turn by several operators for several messages ; the signalling currents for each being so intertwined that the line was never unoccupied

for the smallest fraction of a second. This is achieved by means of a device called a *distributor*.

The function of the distributor is to give possession of the line to a pair of communicators sufficiently long to enable a single letter to be sent and received, and then to pass it on to another pair of operators.

The distributor consists of a revolving arm of metal furnished with

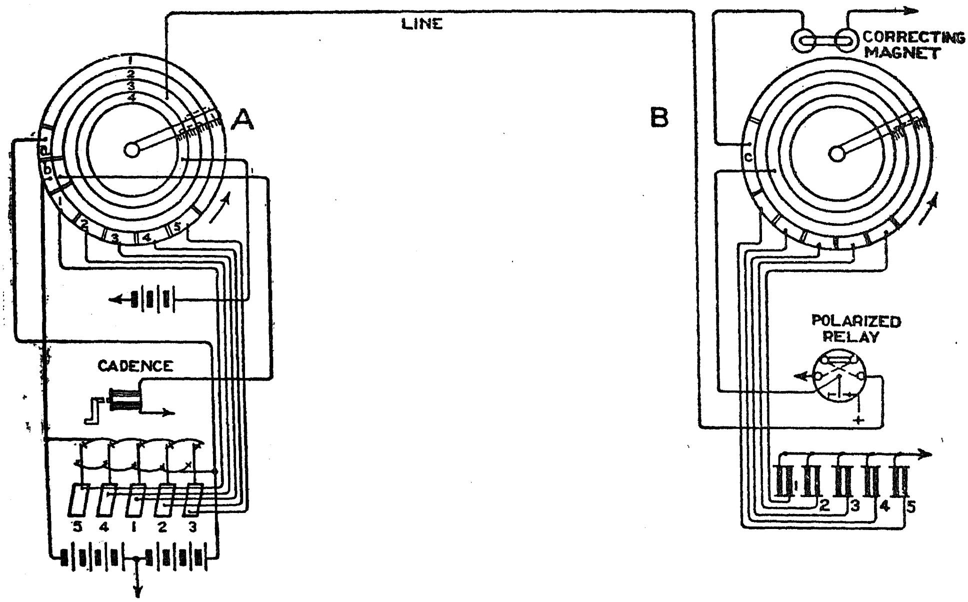
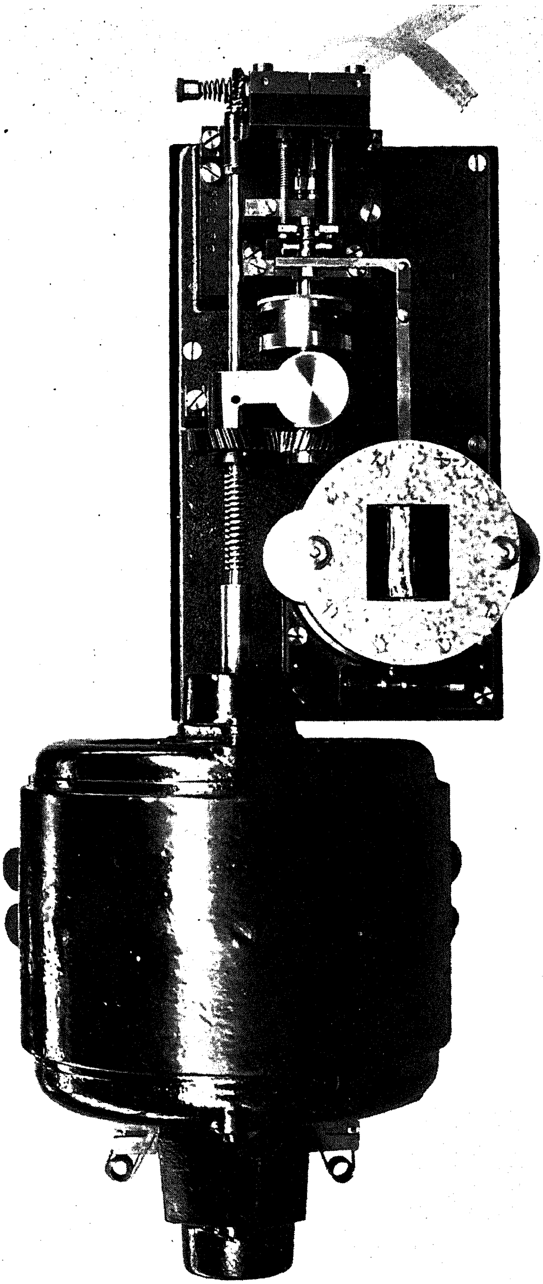


FIG. 11.—Scheme of Circuits and Distributors employed in the Baudot System of Multiplex Telegraphy. At each station there is a distributor having a revolving arm A, which sweeps over and touches the sectors of the distributor, thus sending into the line a succession of five brief currents, positive or negative according as the keys, 1, 2, 3, 4, 5, are held down. At the receiving end (right-hand side) the distributor sends these currents in proper order into the electromagnets, 1, 2, 3, 4, 5, of the receiver. The arms of the two distributors keep in time and step like distant clocks showing correct time.

contact brushes at the end. It sweeps over a metallic ring which is divided into four or six parts, and each of these again into six parts. These metallic sectors are arranged like the stones in an arch, but they are insulated from each other (see Fig. 11). At both ends of the line there is a distributor, and the radial arms of both are caused to revolve at the same rate and keep step with each other like the hands of two distant

PLATE 7.



[*By permission of Messrs. Creed & Co., Ltd.*

A View of a Modern (1920) Creed Receiver (looking down on it from above). This instrument comprises a sensitive telegraph relay (shown in the centre), which is actuated by the incoming signals in the form of electric currents, and this is caused to release the power of an electromagnet, which, in turn, punches a paper tape with perforations on the Wheatstone system, which is an exact replica of the paper tape (see Chapter I., Fig. 1) by which the signals are sent. The mechanism is set in motion by an electric motor (*on the left*).

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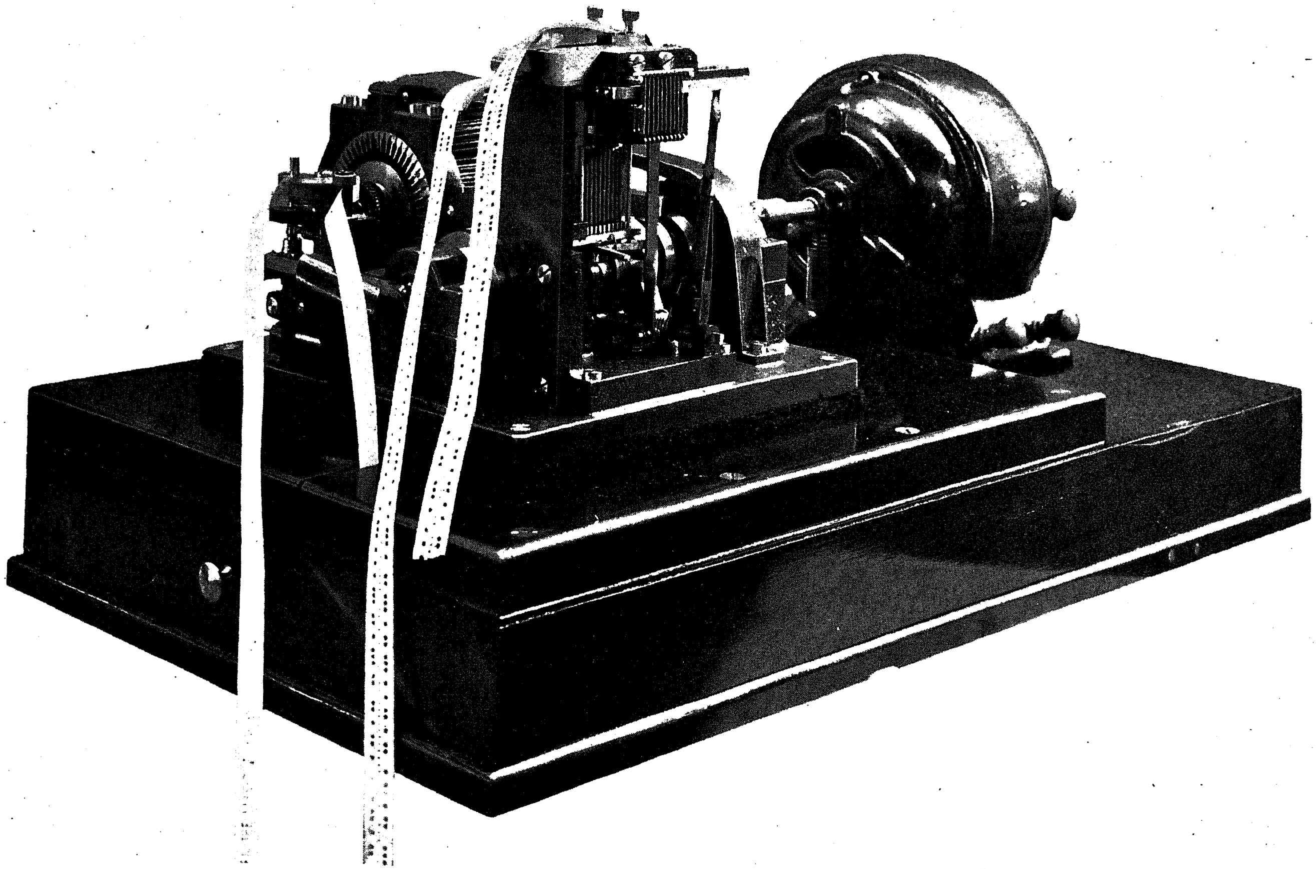
PLATE 8.



[By permisson of Messrs. Creed & Co., Ltd.

A Modern (1920) Creed Printer. In this instrument the punched paper tape which has been prepared by the receiver (shown in Plate 7) is fed through it and by very complicated and ingenious mechanism it prepares from it another paper tape on which the received message is printed in Roman letters. It therefore translates the Morse code signals punched on the first tape into their equivalent letters in Roman type. It is driven by an electric motor.

[To face page 63.

clocks which keep time exactly. The line connects the centre pivot of the arms at the sending and receiving stations.

The alphabet employed by Baudot originated with Gauss and Weber, and is called the five-unit code, because each letter is formed by some

LETTERS	FIGURES	KEYS						LETTERS	FIGURES	KEYS					
		V	IV		I	II	III			V	IV		I	II	III
A	1				●			P	+	●	●		●	●	●
B	8		●				●	Q	/	●	●		●		●
C	9		●		●		●	R	–	●	●				●
D	0		●		●	●	●	S	7/	●					●
E	2					●		T	2	●			●		●
F	5/		●			●	●	U	4				●		●
G	7		●			●		V	'	●			●	●	●
H	'		●		●	●		W	?	●				●	●
I	3/					●	●	X	9/	●				●	
J	6		●		●			Y	3						●
K	(	●	●		●			Z	:	●			●	●	
L	=	●	●		●	●		–	.	●			●		
M	)	●	●			●		*	*	●	●		ERASURE		
N	£	●	●			●	●	FIGURE SHIFT & SPACE.			●				
O	5				●	●	●	LETTER SHIFT & SPACE.		●					
/	1/				●	●									

Fig. 12.—Five-unit Telegraph Code employed in the Baudot System of Multiplex Telegraphy.

permutation of positive and negative currents sent into the line in quick succession, these currents being five in all for each letter. There are thirty-one possible arrangements. Thus, the letter A is one positive followed by four negative currents, the letter E is one negative, then one positive and then three negative. The letter P is five positive currents

in succession (see Fig. 12). These currents are sent out by means of a keyboard with five piano-like keys, which are depressed by three fingers of one hand and two of the other. Each key when depressed sends a positive current into the line, and when the key is up it sends a negative or spacing current. The keys are in connection with five adjacent segments of the distributor, so that as the radial arm sweeps over them it picks up the currents and sends into the line in proper order the combination of five currents, positive and negative, represented by the state of the keys under the operator's finger pressure (see Fig. 13). For each letter the operator depresses some or all of the keys, like playing a chord on the organ or piano. It is obvious, therefore, that each operator must have his fingers on the keys in proper fashion and press all together just at the right instant, before the arm of the distributor sweeps over the corresponding segments. Also he must hold the keys down until this group of currents is collected. The distributor arm revolves at such a rate that each operator has the use of the line for about one-fourteenth of a second. Hence, it is necessary for him to have the proper combination of keys pressed down just at the right instant, not too soon or too late, and not for too long or too short a time.

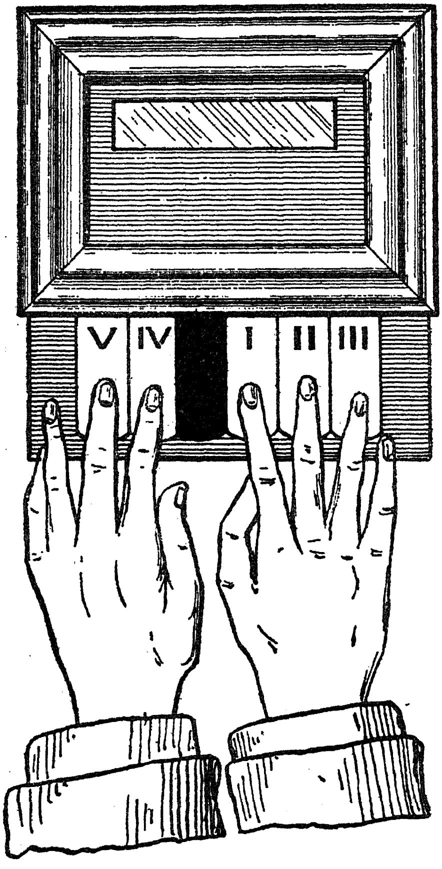


FIG. 13.—Keyboard for Baudot Transmitter.

This is regulated by a device called a cadence tapper, which gives a little sound just in advance of the time when the revolving arm reaches the five contacts on the distributor board, which are connected to the five

keys of the transmitter. At the sound the operator must press his keys. These keys are then held down by an electromagnet until the arm has passed over the segments, when the keys are sprung up again and are ready for another letter (see Fig. 14). The operator has, therefore, to "keep time" with the cadence tapper like a good dancer to the music. This five-unit code of signals is superior in speed to the Morse *dot* and *dash* code.

In so-called quadruple Baudot there is accommodation on the distributor for four sets of sectors connected to four keyboards for four

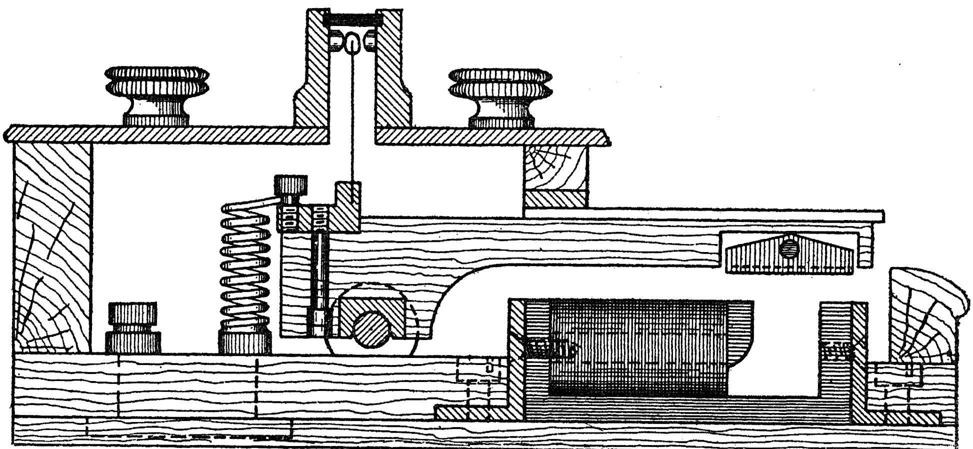


FIG. 14.—Transverse Section of the Baudot Keyboard showing the Electromagnet by which the Key is held down until the Letter Signal is fully sent.

operators (see Fig. 15). In sextuple Baudot six operators can send at once. The line can be duplexed for each pair of operators, so that in sextuple Baudot twelve messages can be passing along the line at once, six in each direction, corresponding to a full traffic possibility of 360 words per minute.

We have next to describe briefly the structure of the Baudot receiver, which is certainly one of the most ingenious telegraphic instruments ever invented (see lower diagram, Plate 9).

We have seen that each letter is formed by the dispatch through the line of five brief electric currents, some positive, some negative. At the receiving end of the line these currents enter the distributor and its

revolving arm delivers them in succession to five electromagnets. The connection is so made that only the positive or marking currents affect the magnets. Each magnet when energised for a brief instant attracts an armature which pushes a rod and shifts a peculiarly-shaped lever, of which there are five (see Fig. 16). Under these levers a wheel rotates, having on its edge two grooves which have their surface indented in a particular

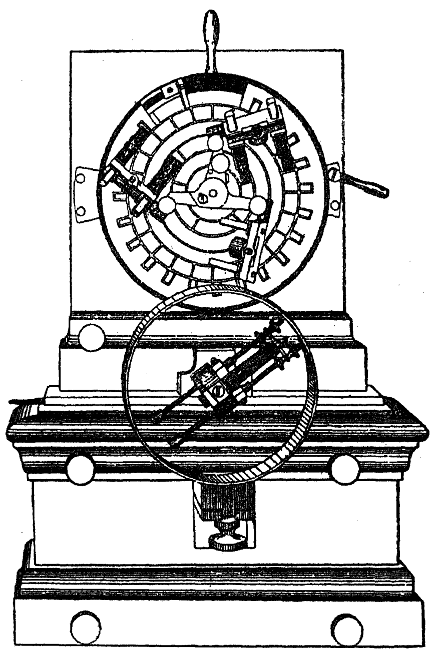


FIG. 15.—Distributor for Quadruple Baudot Telegraphy.

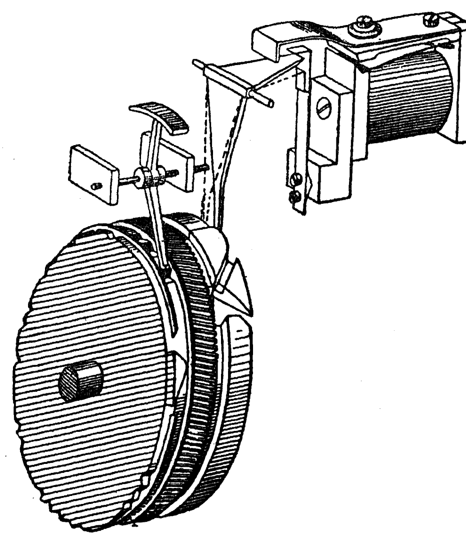
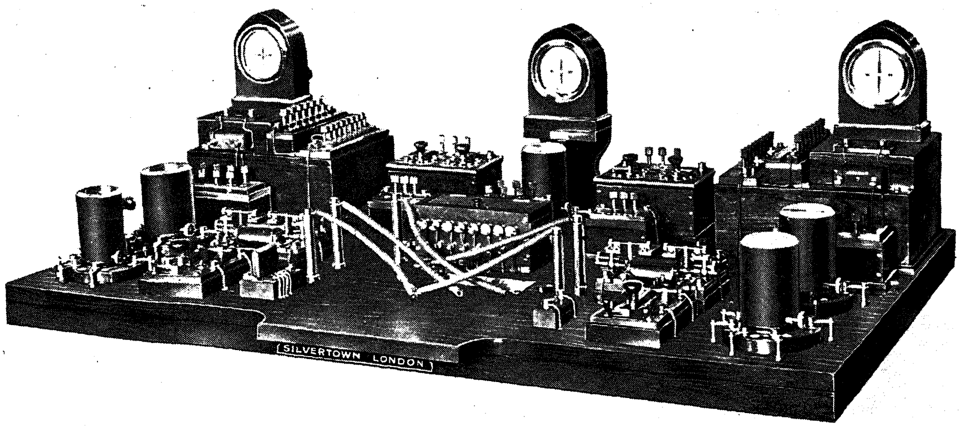


FIG. 16.—A Diagram showing the Recording Wheel and *one* of the five Electromagnets and Levers of the Baudot Receiver.

manner; one of these grooves corresponds to the spacing or negative currents and the other to the positive or marking currents. In the dividing edge between the two grooves of the wheel there is a gate or passage-way. When any one or more of the magnets are energised, the corresponding levers have their ends which rest on the wheel pushed through the gate. The indentations on the bottom of the two grooves are so ingeniously contrived that for every letter in the Baudot alphabet there is a corresponding set of indentations which occupy positions set

PLATE 9.



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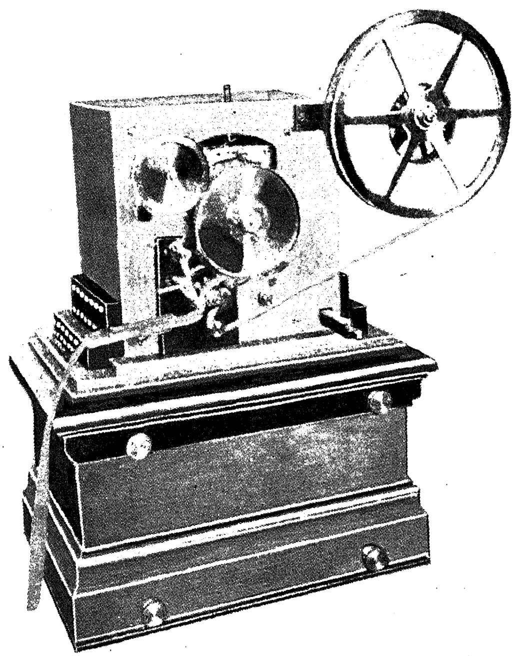
A Fast Repeater Set of Apparatus for Duplex Working. The speed with which signals can be sent through a telegraph line is proportional to the square of the length. Hence, if the line is divided into two equal parts and relays inserted at the junction, the speed of transmission of signalling is increased four times for each half-length, and, therefore, doubled for the whole line. An intermediate station where such relays are established is called a repeater station. (See page 61.)



General View of the Baudot Receiver printing the Message in Roman Letters on Paper Tape.

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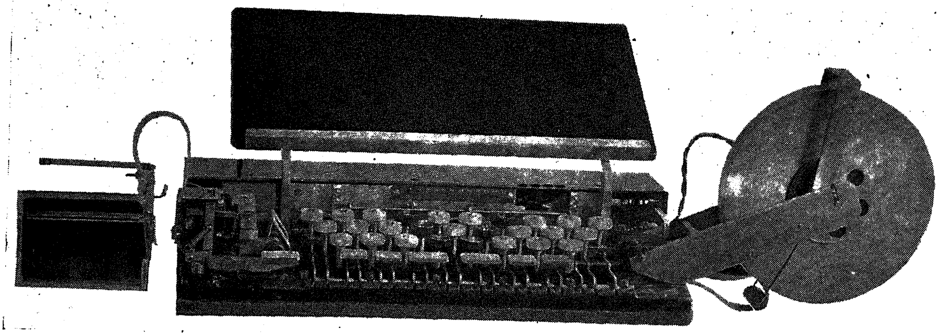
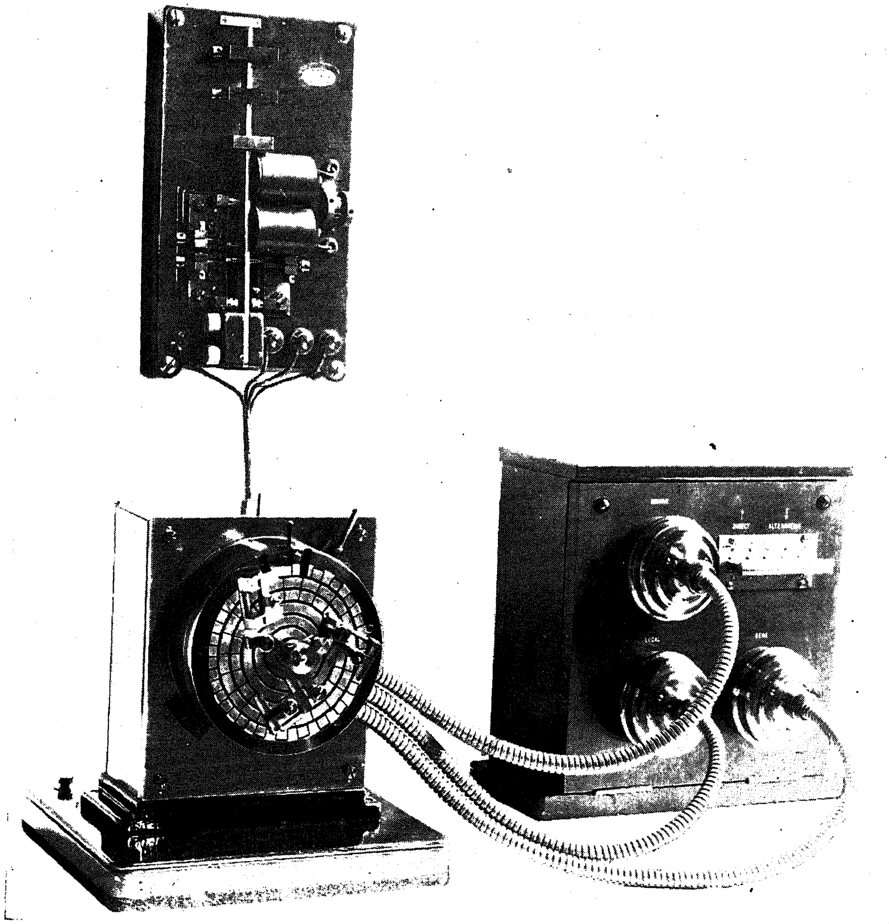
PLATE 10.



The Keyboard Paper Tape Perforator of the Murray Multiplex Printing Telegraph. The loop of perforated tape is seen passing into the transmitter. (See page 69.)



View of the Distributor with Revolving Arm and Synchroniser of the Murray Multiplex Printing Telegraph. (See page 69.)

[*To face page* 67.

all round the wheel. On the same shaft which carries this doubly-grooved wheel there is a printing wheel having the letters of the alphabet engraved on its edge, and arrangements for pressing up against this wheel a strip of paper, so as to print some letter upon it. When the ends of the above-mentioned levers all drop into a set of indentations at the same instant, a mechanism is set in operation which presses up the paper strip and prints that letter which corresponds in the Baudot alphabet to the particular group of electric currents which have set the levers in the position so to act (see Fig. 12). Every time, therefore, that the sending operator presses his fingers on the five-key board, depressing one or more of the keys and thus sending out a group of five electric currents one after the other into the line, the receiving mechanism is actuated and at once prints on the moving paper strip the corresponding letter in Roman type. A skilled operator can send 150 letters a minute in this manner.

The tape is then cut up into short lengths and gummed to a message form and sent out to the recipient. One important point remains to be explained. It will be evident that everything depends upon the two rotating arms of the distributors at the sending and receiving stations keeping exact step with each other, not merely rotating at the same speed, but touching corresponding sectors at the same instant. This is managed as follows. On the transmitting distributor there are two adjacent sectors which are connected to the positive and negative poles of the battery. As the arm sweeps over these it picks up the currents and sends them along the line. The receiving distributor has a wide sector placed in the same relative position on its board as the two battery sectors on the transmitter board. When the receiving distributor arm passes over this wide sector it picks up the current and sends it into the coils of an electromagnet, which actuates a brake retarding slightly the speed of the receiving distributor arm. The rotating arms of both distributors are rotated by powerful clockwork and are adjusted and kept nearly constant in speed by sensitive governors. The speed of the receiving arm is set to be a little greater than that of the transmitting arm. Hence, the former gains on the latter. When the receiving arm is just passing the wide sector at the instant when the distributor arm is on the similarly-placed battery sector a brief electric current passes into the electromagnet,

which then sets in operation a brake and slightly retards the speed of the receiving distributor arm. If the latter is retarded too much the braking currents cease to be received at each revolution and the receiving arm again gains and catches up the transmitting arm. By this ingenious arrangement the two distributor arms at very distant places are kept revolving like the hands of two clocks, both of which keep exactly Greenwich time (see Fig. 11).

The Baudot telegraph met with extraordinary success immediately on its introduction into France, and was soon adopted in nearly all European countries as well as in India and South America.

It has been extensively used in the British Telegraph Service. We can say that outside of hand-worked Morse printers and throughout the world only the three systems of Telegraphy, viz.:—Wheatstone automatic, the Hughes printer, and the Baudot printer, have come into any general extensive use. The one serious defect in the Baudot is the nervous strain it puts upon the sending operator to keep exact time with the cadence tapper, and this in practice reduces the actual speed of sending to twenty words per channel or per keyboard in each direction.

Efforts have been therefore made to meet this difficulty. One of the most successful is the multiplex printing telegraph of Mr. Donald Murray. This system follows on the same general lines as the Baudot, but differs from it in important particulars. The Murray multiplex printing telegraph, which is a development of the French Baudot multiplex, transmits four

NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THE PARTY.

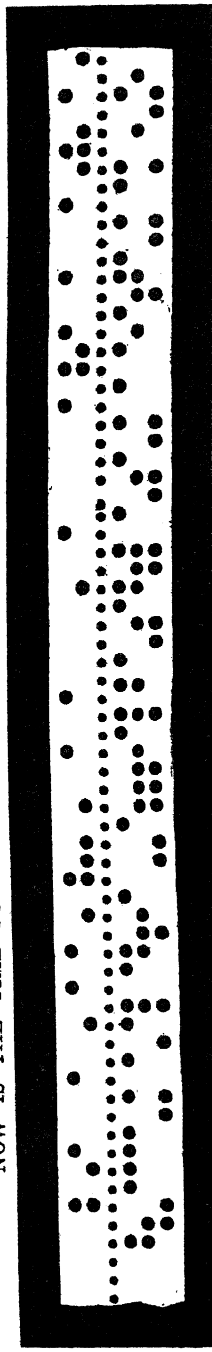


FIG. 17.—Punched Paper Tape used with the Murray Multiplex Printing Telegraph. Each letter consists of a group of one to five holes punched transversely to the tape, and the row of small equi-distant holes is for moving the tape through the transmitter.

messages simultaneously each way on one telegraph wire. Four operators at each end of the line typewrite on four keyboards, and the messages are automatically page-printed at the other end of the line on four page-printers, from which four attendants take off and check the messages ready for delivery. On the multiplex eight operators are employed at each end of the telegraph line, and they do as much work as sixteen operators at each end of a number of Morse wires.

There are revolving distributors at each end of the line which divide the time between two to eight operators as in the Baudot, but in place of hand-sending Murray employs a punched tape with the holes for each letter placed crossways on the tape. The Murray telegraphic alphabet is similar to, but not quite identical with, the Baudot (see Fig. 17). This punching is done by a kind of typewriter which makes the proper group of holes for each letter in the tape when a key on it is depressed (see Plate 10, page 67). The punched tape then passes through a transmitter which takes the place of the Baudot five-key board. The keyboards perforate paper tape with groups of holes representing letters and figures, and this perforated tape passes through a transmitter alongside each keyboard. The transmitters are entirely automatic, and start and stop automatically in accordance with the amount of perforated tape available for transmission. The operators have nothing to do but type on the keyboards. The points of perforation and transmission are only one inch apart, and there is only four seconds delay between starting to perforate and starting to transmit. The keyboard mechanism provides for invisible correction of errors before transmission, a back-spacing key enabling errors to be instantly punched out of the tape so that no trace of the correction, not even a space, appears in the printed message at the other end of the line.

The distributors are rotated synchronously by a form of electric motor called a phonic wheel, which keeps the speed constant, and the rotating arms at the two stations are kept in step by an electromagnet energised at each revolution by a current (see Plate 10, page 67). This magnet shifts one distributor arm forward or backward if it gets out of step.

The Murray receiver prints the message directly on a telegraph form in page fashion so that it is instantly ready to be sent out to the proper recipient (see Plate 11). The speed ranges from thirty to sixty words per

minute per channel according to the length of the line and the pressure of traffic. The Western Union Telegraph Company has installed the multiplex all over the United States, and it is working on a Western Union line between New York and San Francisco, 3,325 miles, giving four channels each way simultaneously, each channel transmitting at the rate of thirty-eight words a minute, all on one wire.

It is impossible in the space at disposal to do full justice to these ingenious forms of printing telegraph such as the Baudot and the Murray.* The demands of modern life for increased speed and accuracy in telegraphy make multiplex high-speed working of great importance.

In 1913 the Postmaster-General appointed a committee to consider the question of high-speed telegraphy, and their full report was published in 1917 by His Majesty's Stationery Office.

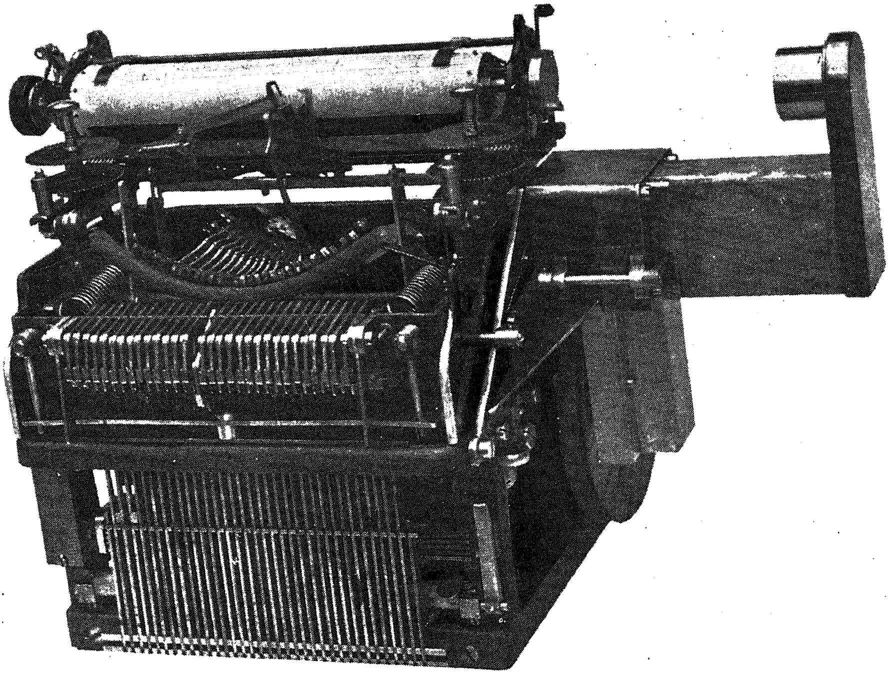
Very briefly, their conclusions were that printing telegraphs on the multiplex principle are superior to the Wheatstone automatic for ordinary inland telegraphy. Page printing of the received message is to be preferred to tape printing. The five-unit code is better than the Morse code, and the application of ordinary typewriter keyboards in the Baudot system is desirable.

The future of inland telegraphy is therefore bound up with the improvement and simplification of machine telegraphy, and the telegraphic instrument of the future may be said to be a kind of typewriter split into two parts, viz., a keyboard at the transmitting station and a page printing receiver at the receiving station, the two being connected by a wire through which combinations of positive and negative electric currents are being rapidly sent for each letter transmitted.

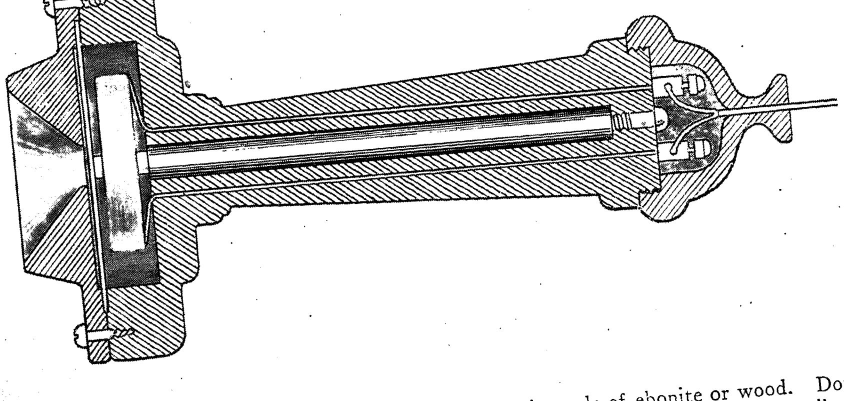
We must next briefly consider the improvements in submarine telegraphy since 1870. Lord Kelvin, then Sir William Thomson, designed the syphon recorder in 1867 in such perfect form as a receiving instrument that no important improvement has been made in it since, except perhaps the method of decreasing the friction of the glass pen on the paper tape by continually lifting the tip from the tape by means of an electromagnetic

* The reader may be referred to a book on practical *Telegraphy*, by Mr. T. E. Herbert (Messrs. Whittaker & Co.), and to one by Mr. H. W. Pendry, for fuller information on the Murray and Baudot systems of machine telegraphy.

PLATE II.



The Page Printing Receiver of the Murray Multiplex Printing Telegraph.



A section of Bell's Magneto Telephone. The outer case is made of ebonite or wood. Down the centre passes a steel bar magnet, on the end of which (to the left) is wound a coil of silk-covered copper wire. The pole of the magnet is very near to a thin sheet iron disk (shown in section) called the diaphragm. The sound waves of the voice are converged on the diaphragm by a conical mouthpiece. (See page 82.)

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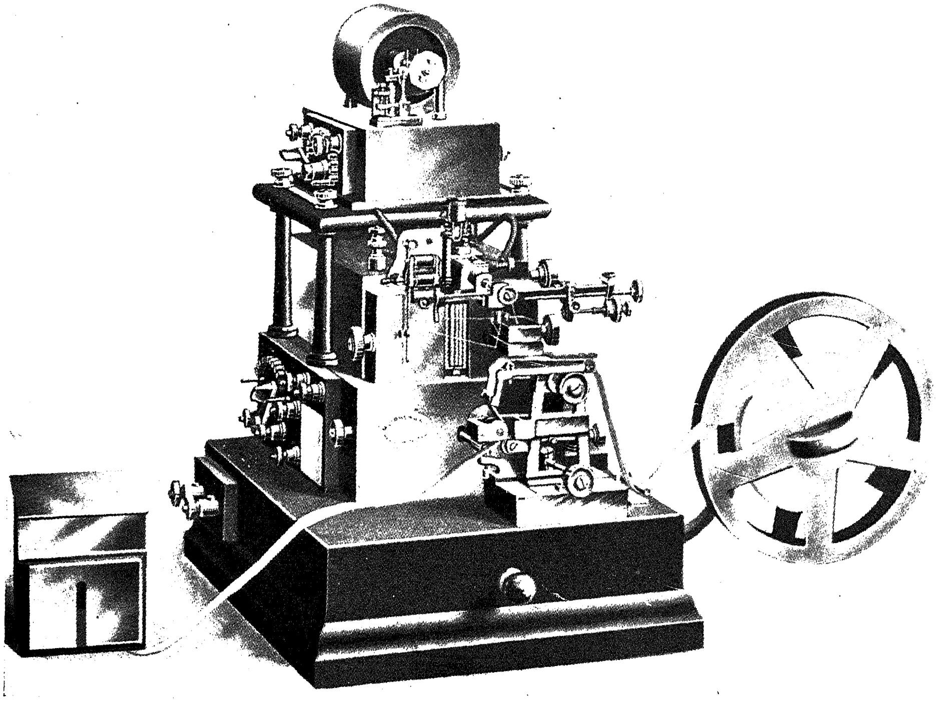


[By permission of Messrs. Muirhead & Co.

Modern Syphon Recorder of Lord Kelvin used in Receiving Signals on long Submarine Cables.

A Double Head Bell Telephone Receiver with Watch Type of Receiver. The two receivers are connected by a steel elastic strip, which is placed on the head so as to press the two receivers against both ears of the user. (See page 82.)

[To face page 71

vibrator. The line drawn on the paper by the ink-filled syphon pen is then a closely adjacent series of dots and not a truly unbroken line. This has the effect of greatly reducing the current required to operate the instrument, and therefore increases the speed of sending signals (Plates 12 and 13, pages 71 and 78.)

In 1870 Dr. Alexander Muirhead invented and put into practice, in

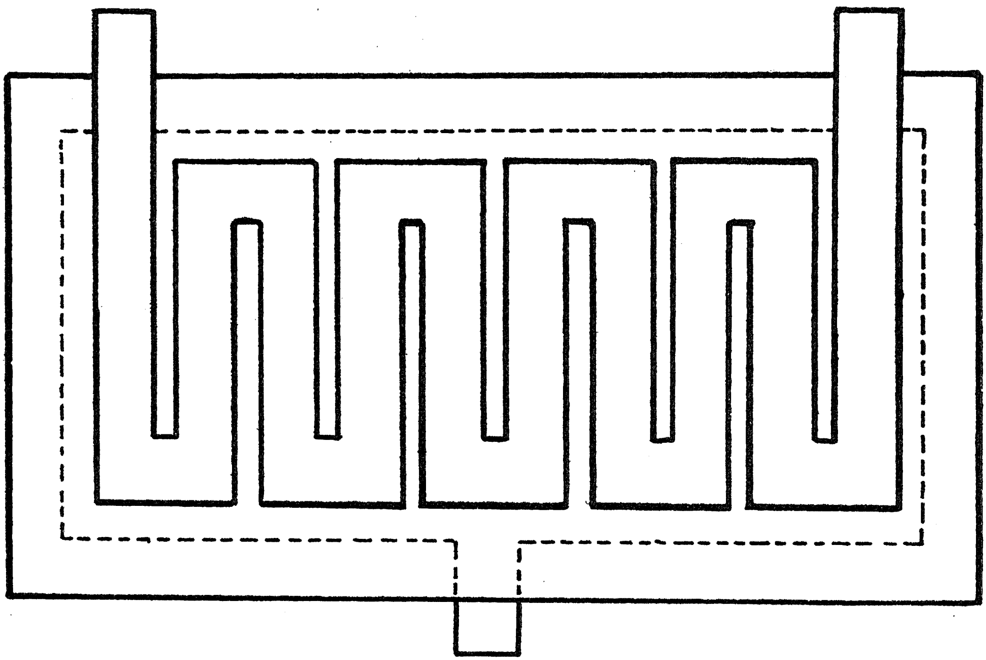


FIG. 18.—A Single Sheet of the Condenser which is built up into a Muirhead Artificial Cable. The dotted line is the outline of the rectangular sheet of tinfoil on the back side of the paraffined paper sheet.

co-operation with Mr. Herbert Taylor, a plan of duplexing cables so that two messages could be sent at once in opposite directions. This doubled at one blow the income-earning power of a cable.

A deep-sea submarine cable is an expensive article costing at present at least £300 per mile or more, whilst the life of the cable is at best about forty to fifty years. Hence every effort has to be made to get through it traffic enough to make it pay for itself, not only interest on capital outlay and depreciation, but cost of repairs and dividend as a business concern.

In order to duplex a cable we have to provide an artificial cable which possesses not only electrical resistance but electrical capacity as well. Dr. Muirhead did this by his invention as follows :—

Sheets of paper are immersed in melted paraffin wax and a sheet of tinfoil not quite so large as the paper fixed to one side. On the other side a sheet of tinfoil, cut in a sort of zig-zag as in Fig. 18, is fixed. These sheets are covered with other sheets of paraffined paper and a number of them put into a box. All the complete sheets of tinfoil are connected together and the zig-zag tinfoil strips are joined up in series.

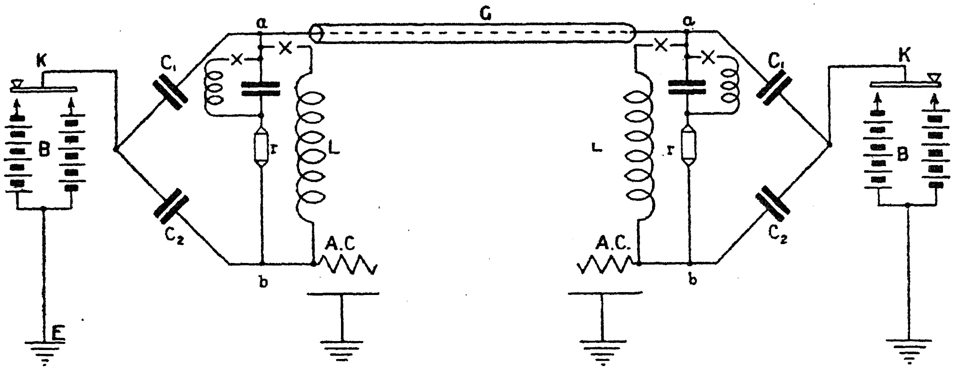


FIG. 19.—Arrangements for Duplexing by the Bridge Method a Submarine Cable. B is the battery, E the earth connection, K the sending key, C_1 C_2 the bridge condensers ; *r* is the syphon recorder, G is the submarine cable, and AC the artificial cable. L is an inductive coil which shunts the recorder and assists to sharpen the signals.

This conductor then possesses electrical resistance to the flow of current through it, and also electrical capacity or power of storing electric energy. By adjusting the size and shape of the tinfoil sheets such a conductor may be made to resemble exactly any given submarine cable. The electric resistance of such a cable is generally about 4 to 10 ohms per mile, and its capacity about $\frac{1}{3}$ microfarad per mile. The speed at which signals can be sent through the cable is inversely proportional to the product of its total capacity and total resistance of the cable.

The arrangements for duplexing are then as shown in Fig. 19.

The current from the battery B splits at a certain junction, part going through a shunted condenser C_1 into the actual cable, and part through

a shunted condenser C_2 into the artificial cable A.C. By a shunted condenser is meant a condenser whose terminals are joined by a resistance wire.

The receiving instrument or syphon recorder *r* is connected between the beginning of the actual and of the artificial cable.

The arrangement at both ends is similar. The result is that an outgoing current is divided equally between the real and the artificial cable,

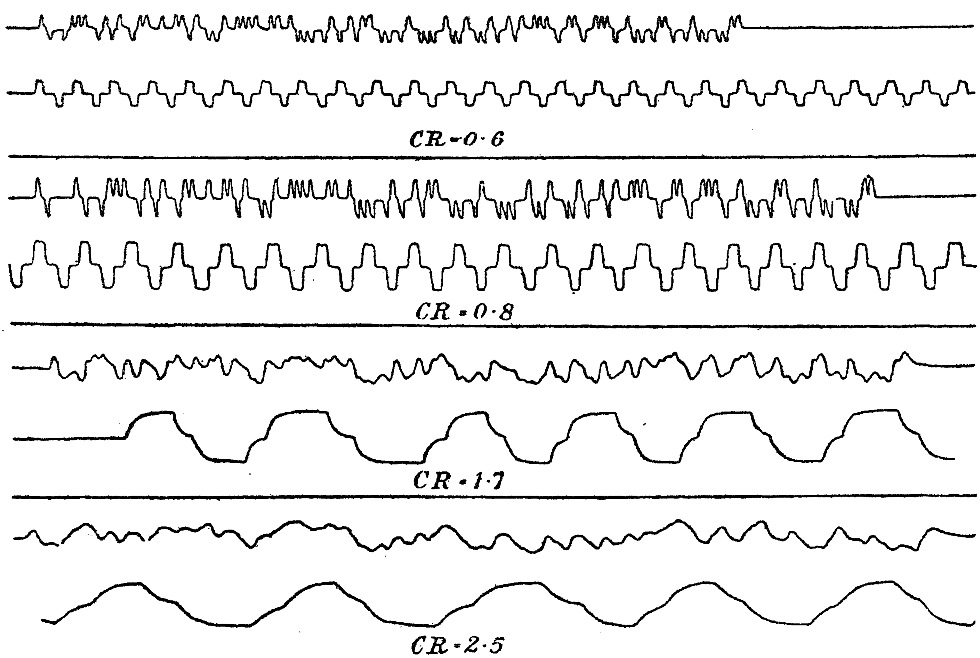


Fig. 20.—Samples of Syphon Recorder Signals received through Submarine Cables of various lengths and constructions. Generally speaking, the longer the cable, the less sharp and well-defined are the signals. The signals shown on the two top lines are those through a short cable, and those on the two bottom lines through a long one.

and the terminals of the receiving instrument remain at the same potential or pressure and hence it is not affected. But an incoming current passes through the syphon recorder coils and goes to earth through the artificial cable, and hence the receiving instrument records a signal. This arrangement is called a bridge duplex, and by it the earning power of a cable is doubled. The problem of increasing the message-carrying power of a cable is intimately connected with the invention and improvement of

cable relays and magnifying repeaters. Lord Kelvin showed, as explained in the introductory chapter, that when one end of a cable is connected to a battery the potential or electric pressure at the other end does not rise up suddenly, but grows up gradually, as shown by the ordinates of a curve of arrival. The more sensitive the receiving instrument the sooner will it be affected. Similarly, when the battery is removed at the sending end the current at the receiving end dies down slowly.

Hence, if we apply alternately the positive and negative battery poles, so as to send into the cable currents which deflect the distant syphon recorder coil first one way and then the other, the record on the tape, if the cable is very short, is as in the top row of Fig. 20. If, however, the cable is long, then the signals are very rounded and prolonged as in the lower rows of Fig. 20. It should be explained that in signalling with the syphon recorder the *dot* is signified by a sudden deflection of the coil to one side and the *dash* by a similar one to the other. In other words, in cable telegraphy the *dot* and *dash* signals have equal duration but are made by brief currents in opposite directions in the cable.

The problem, therefore, of increasing the speed of sending is that of designing instruments capable of being affected by very feeble electric currents, but which are so made that their movements reverse the direction of a current suddenly through another syphon recorder so as to produce magnified and sharply defined tape records easily read.

A number of such cable relays have been devised which greatly increase the speed of signalling as compared with direct working on the syphon recorder. Mr. S. G. Brown, Mr. Heurtley, and Mr. Axel Orling have made notable contributions to this subject.

In the Brown drum cable relay there is a silver drum divided into three separate parts by mica subdivisions. This drum is revolved by an electric motor. On the drum rests the bent end of a fine phosphor-bronze wire included in a glass tube. This wire is connected to the coils of a syphon recorder by silk threads, so that the smallest movement of the coil deflects this wire to right or left. The mica divisions in the drum are placed near the centre and divide it into two outside wide parts and an intermediate, narrow " no man's land " between them. The tip of the stylus or wire rests normally on this intermediate part, but when deflected

the tip rests on one or other of the outside parts (see Fig. 21). These outer drum sections are connected by rubbing contacts with the terminals of a battery, so that the stylus or wire as it moves from side to side is connected first to one pole or to the other of the battery. If the drum did not revolve the friction of the wire point on the metal surface would

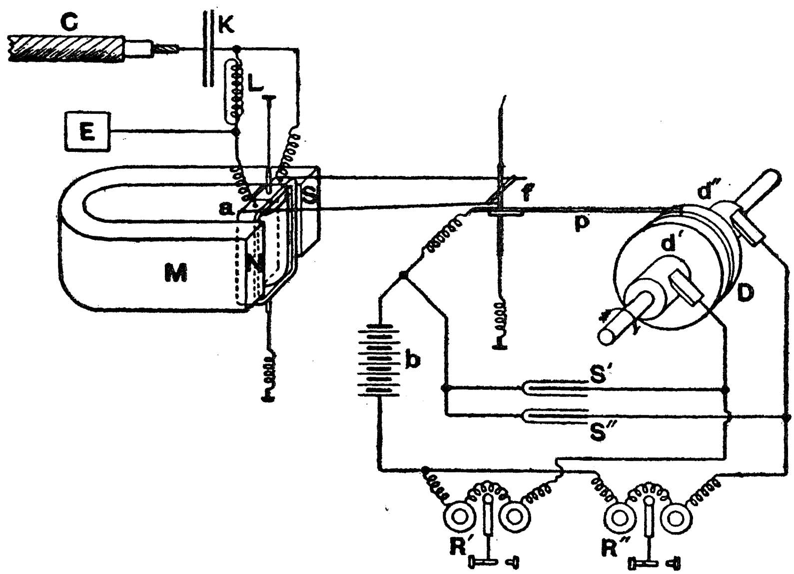


FIG. 21.—Arrangements of the Drum Cable Relay of Mr. S. G. Brown. C is the end of the cable. The feeble electric currents coming out of it enter the coil *a* of a syphon recorder and cause slight movements of it to right or left. These are caused to make larger movements of the phosphor-bronze needle *p*, the tip of which rests on the revolving silver drum D. The motions to right or left of this needle throw the current from a local battery *b* through one or other of two local relays R′ or R″, which, in turn, operate the recording instrument.

be by no means negligible. If the drum revolves quickly this reduces the friction and enables quite a small force applied to the stylus to cause it to move from side to side. This action is made to send an electric current from a local battery through the coil of a syphon recorder in one direction or the other and so magnify and record the feeble received electric currents coming out of the cable. Another very ingenious relay is that of Orling. He found that a jet of acidulated water falling out of the end of a glass tube is deflected to one side or

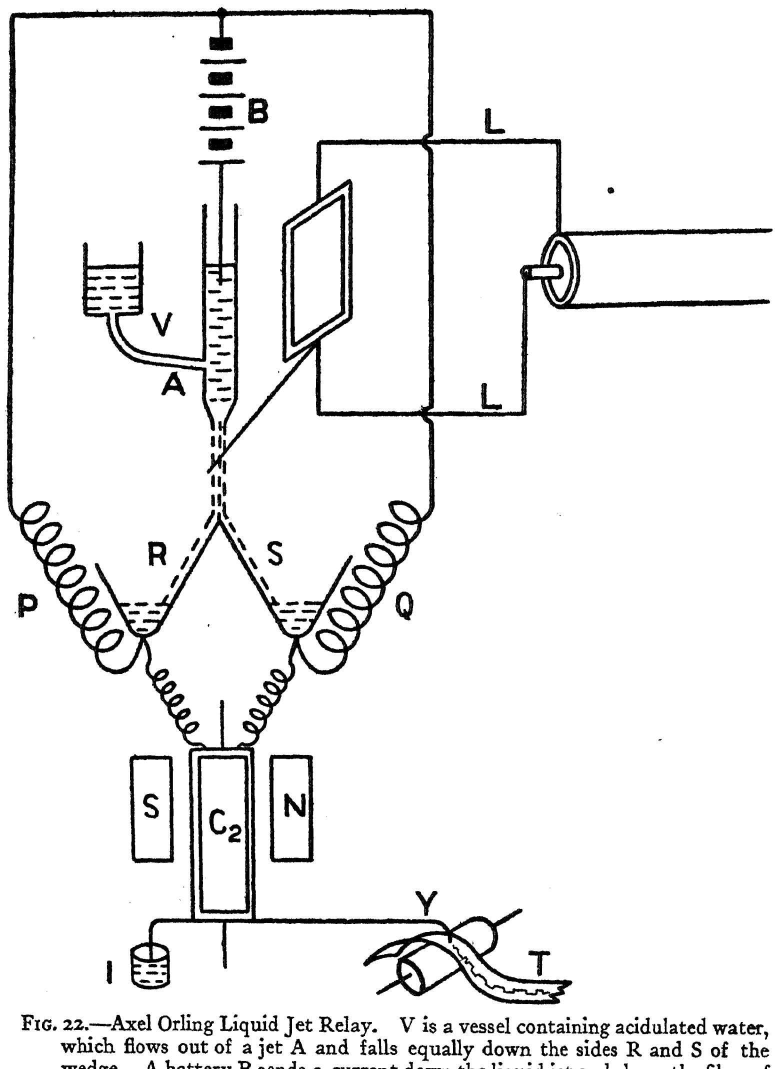


FIG. 22.—Axel Orling Liquid Jet Relay. V is a vessel containing acidulated water, which flows out of a jet A and falls equally down the sides R and S of the wedge. A battery B sends a current down the liquid jet and down the films of liquid R and S, returning through the wire resistances P and Q. If the liquid films R and S are equal in resistance, the coil of the syphon recorder C_2 is not moved. If, however, the signalling currents coming out of the cable by the wires L deflect the coil of the attached syphon recorder (the magnet is not shown in the diagram), then the stiff fibre attached to it displaces the jet of liquid to one side, and this renders the films of liquid of unequal resistance, and therefore a current from the battery B passes through the syphon recorder coil C_2 and makes a magnified record. Movements of the fibre touching the jet too small to see with the naked eye can thus make good records.

the other by the lateral pressure of a quartz fibre moved to a hardly visible extent against the jet.

He allows such a jet of liquid to fall upon the edge of a wedge-shaped piece of celluloid in such fashion that it streams equally down the two sides of the wedge on to pieces of carbon which form electrodes (see Fig. 22). If the jet of liquid is ever so little displaced, one side of the wedge has more liquid on it than the other. This movement of the jet is effected by the pressure of a little glass rod attached to a coil like a syphon recorder coil, which is suspended between the poles of a strong magnet. A very feeble electric current through this coil will cause it to turn in the field one way or the other. Through this coil the feeble signalling currents coming out of the cable pass and deflect it one way or the other. The rod attached to the coil then presses transversely on the liquid jet and displaces it to one side or the other. If another and stronger electric current is sent down the jet of liquid it will normally divide equally between the two equal streams of liquid flowing down the two sides of the wedge. When, however, the jet is displaced and the liquid streams become unequal in resistance, this equality of division in the electric current is disturbed. By well-known methods this inequality may be made to send a current through a syphon recorder, which marks on a tape a very magnified representation of the current variations through the coil of the Orling relay. In this manner currents coming out at the receiving end of a long cable which would be too feeble to make visible records if sent direct into a syphon recorder can be magnified so as to give good readable records. Hence, the cable speed can be greatly increased.

Cable speeds are generally measured in *letters per minute*, which can be transmitted, subject to these being fairly easily read on the recorder paper tape.

If the whole electrical capacity of the cable measured in units, called microfarads, and denoted by the symbol K, is multiplied by the whole resistance of the cable conductor measured in ohms and denoted by R it gives a numerical product called the cable KR. The number of readable letters which can be transmitted per minute varies directly as a constant, called the *cable constant*, and inversely as the KR of the cable

Thus, for example, a certain Atlantic cable has a capacity of 886 microfarads and a resistance of 6,998 ohms. Hence, its $KR = 886 \times 6{,}998 = 6{\cdot}2$ million. For this cable for certain receiving instruments the *constant* is 700 million. Hence, the letter speed is $700 \div 6{\cdot}2 = 113$ letters per minute.

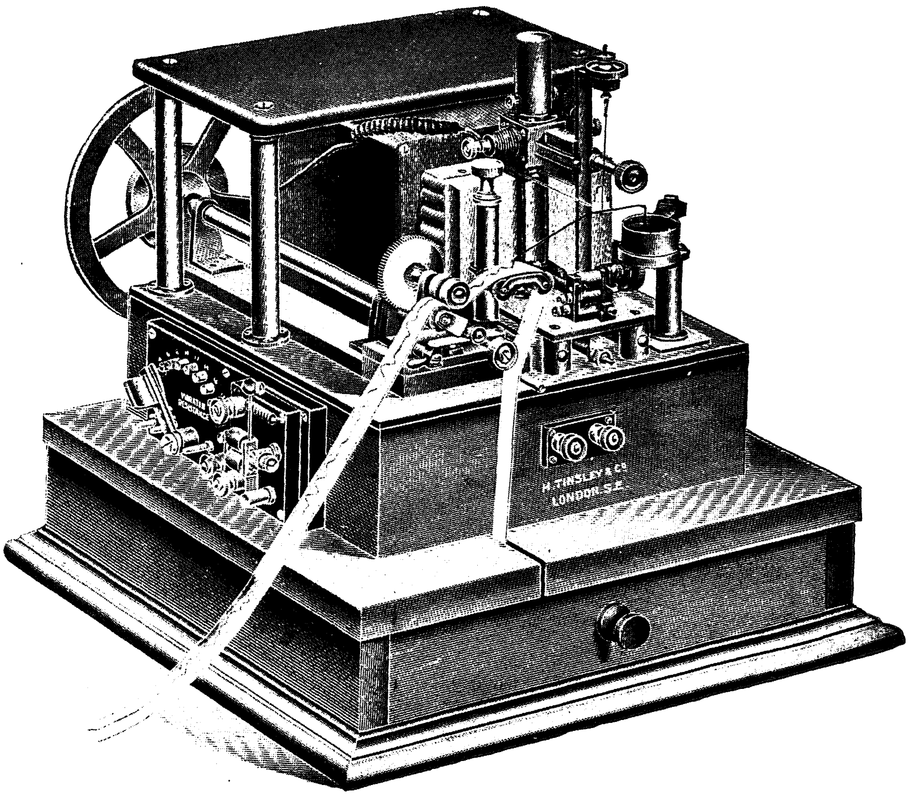
The effect of using more sensitive relays or magnifiers is to increase the cable constant to values of 1,200 or 1,500 million or more. Thus, for a certain Atlantic cable with a $KR = 4$ million, the letter speed when using an Orling relay rose to 300 letters per minute transmitted.

Space will not permit of any very prolonged account of the improvements made in the last half century in submarine cable making, laying, and working. It has always been a notable British industry.

Before the European War, 1914—18, Great Britain was connected with France by eight submarine telegraph cables, with Belgium by three, Holland three, Germany six, and Norway by two, all worked jointly by the combined Governments. The North Atlantic Ocean is crossed by seventeen cables owned by various companies. South Africa (Cape Town) is connected directly by the Eastern Telegraph Company with Great Britain by a cable touching at Madeira, St. Vincent, Ascension, and St. Helena. The Eastern Extension Company has cables from Durban to Perth (Western Australia) and Adelaide (S. Australia), *via* Mauritius, Rodrigues, and Cocos Keeling Islands. Another set of cables connect New Zealand and Australia with Canada. In 1902 a Pacific cable was laid by the Imperial and Dominion Governments from Vancouver to New Zealand and Queensland, *via* Fanning Island, Fiji and Norfolk Island. This cable provides a completion to an all-British cable route encircling the earth, with the other cables connecting up all the British Dominions.

The copper conductor, which is the vital nerve axis of the cable, is now always made of stranded copper wire, and the gutta-percha insulation is protected from the attacks of an organism called a teredo, which appears to have an appetite for gutta-percha, by a winding of brass tape. The outer steel wire armour is made especially heavy near the shore ends to obviate injury by ships' anchors.

A quick-signalling cable is generally a heavy one because it has a relatively large copper core or wire. In Plate 14 are shown illustrations



Syphon Recorder for Receiving Signals on long Submarine Cables as made by Mr. H. Tinsley.

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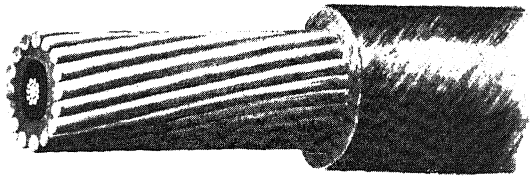
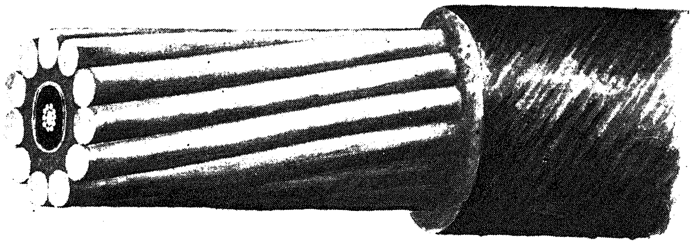
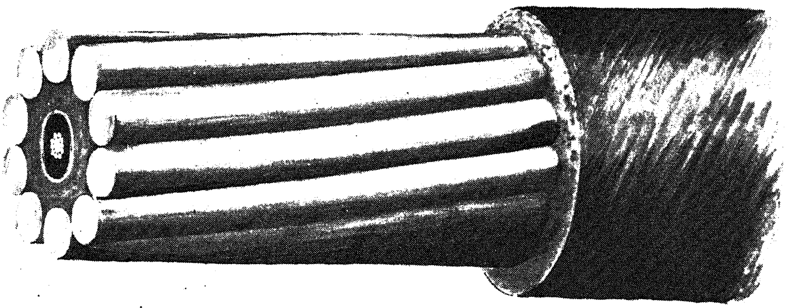
PLATE 14.







[By permission of Messrs. Siemens Bros.

Full-size Views of Portions of long Submarine Cables. The top view is the deep-sea portion, the middle view is the intermediate, and the bottom view is the heavily armoured shore end. The small white dots in the centre of the end section are the copper conductors, the black surrounding it is the gutta-percha insulation; then comes the brass tape, more hemp, and over that the stout steel wires, called the armour. The protective woven covering is cut back to show the twisted armour wires.

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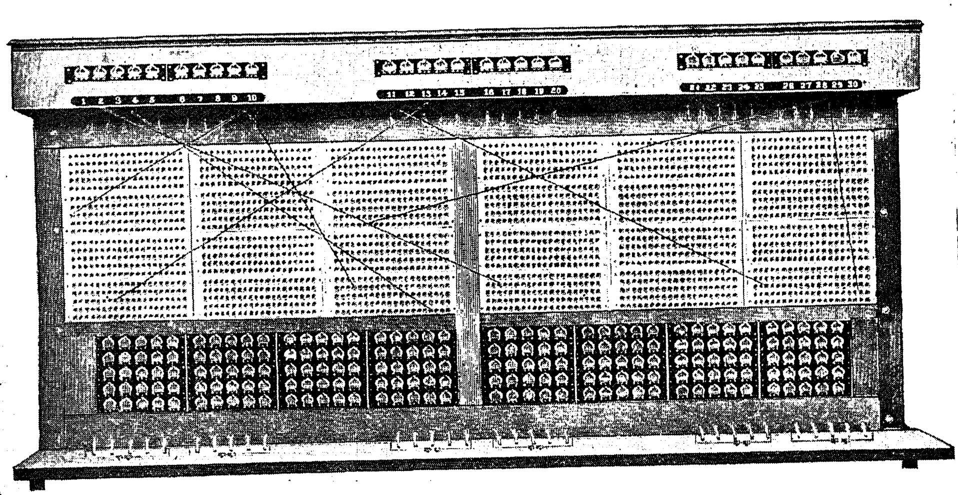
PLATE 15.

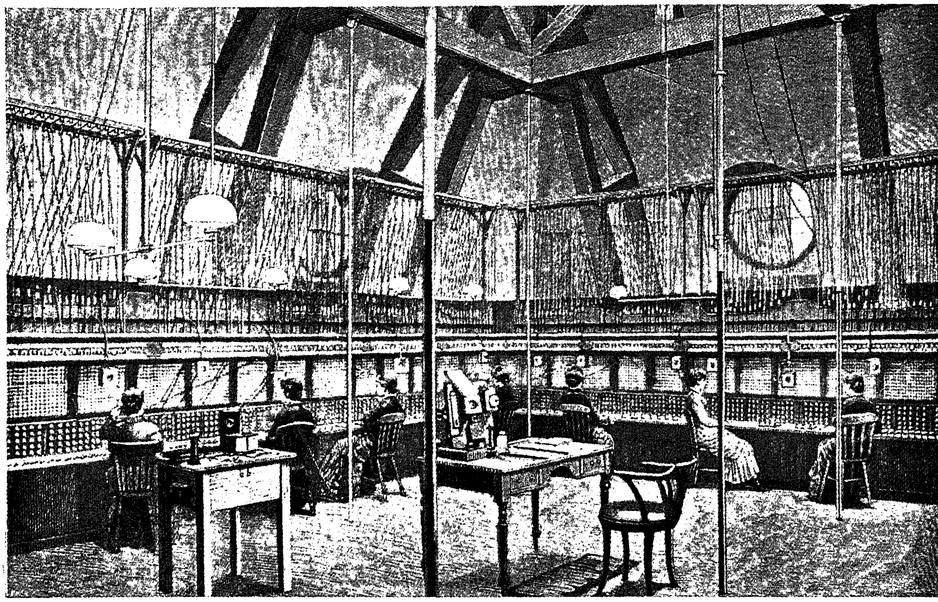
A Subscriber's Telephone Set, comprising a Bell Magneto-receiver (on the hook) and a solid-back carbon granule Transmitter (on the pillar), as used with the Common Battery system.



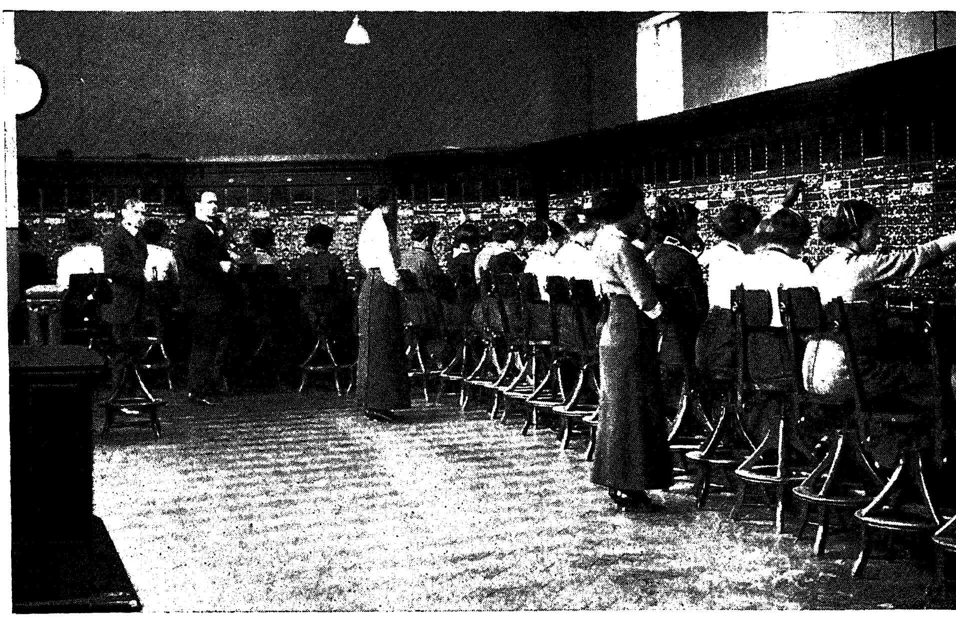
View of part of a Multiple Telephone Exchange Switchboard. The bottom set of plugs or "jacks" are the terminations of "calling" subscribers' lines, and all those above are the rest of the subscribers' terminals.

[To face page 88.

PLATE 16.

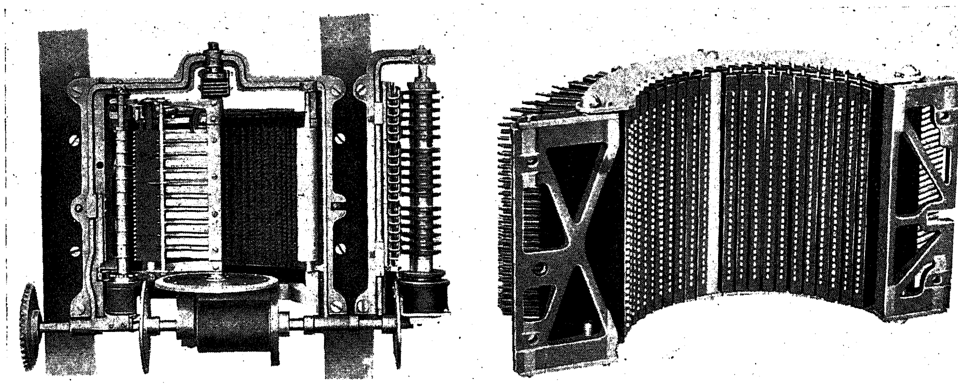


A View of the Interior of an early type of Manual Telephone Exchange. The telephone girls are shown attending to subscribers' calls and making the required connections at the switchboards.



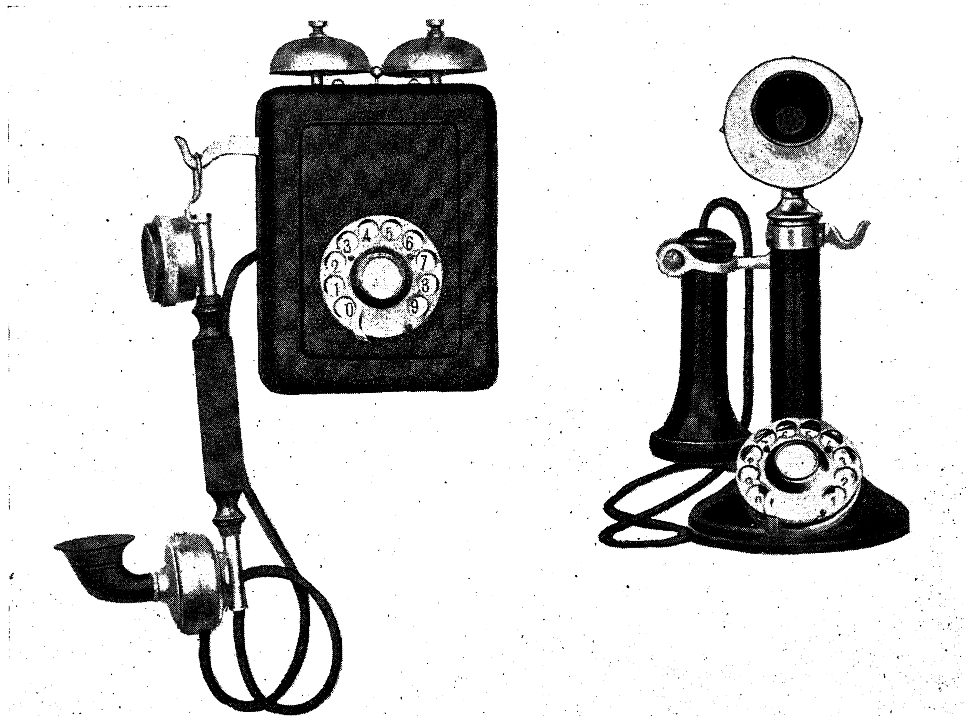
View of the Interior of a modern Manual Telephone Exchange, showing the girl operators and superintendents making the required connections of subscribers.

PLATE 17.

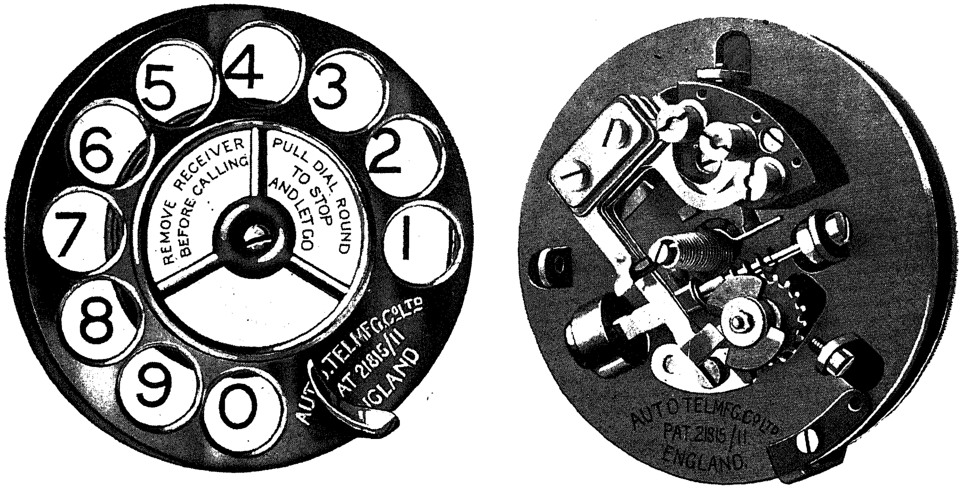


(*a*) (*b*)

Selector Switch, Western Electric Company's Type, showing in (*a*) complete switch with contact brushes or wipers, and in (*b*) the terminal contacts of various telephone lines arranged on a cylindrical arc. The brushes are caused to move over the contacts by mechanical power supplied by an electric motor, but they are started and stopped at the required place by an electro-magnetic clutch.

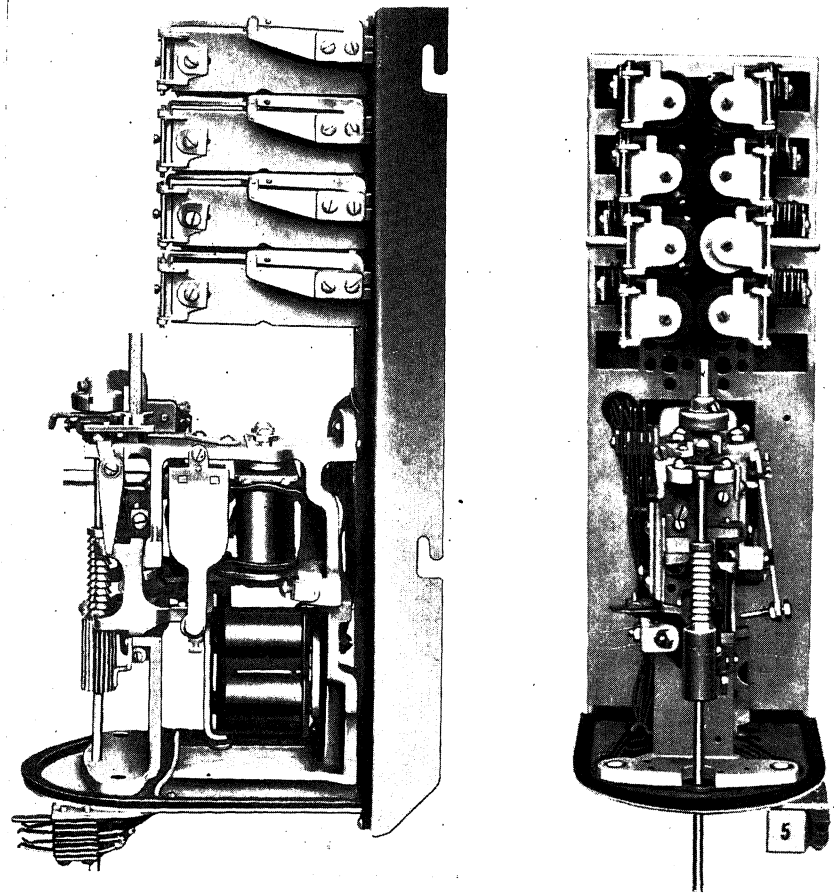


Subscriber's Table or Wall Telephone Set, with Dial for calling up a required number in an Automatic Telephone Exchange.



[*By permission of the Automatic Telephone Manufacturing Co.*

Details of the Calling Dial on the Subscriber's Telephone Set used in connection with an Automatic Telephone Exchange.



[*By permission of the Automatic Telephone Manufacturing Co., Ltd., Liverpool.*

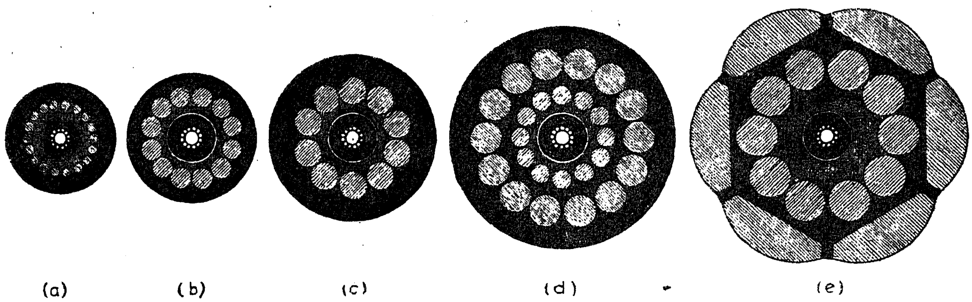
Two Views of a Strowger Selector Switch as used in a type of Automatic Telephone Exchange.

[*To face page* 89.

of samples of deep-sea submarine cables made by Messrs. Siemens Bros., of Woolwich. The copper conductor is shown by the small white circles in the centre, and the outer wires are the steel armouring. The thin cable is the deep-sea portion, and the thicker samples are the heavier and strong shore ends near the coast line or in shallow water.

Sections of a modern Atlantic cable are also shown in Fig. 23, the small sections (on left) being the deep-sea portions and the larger sections (on right) are the shore ends heavily armoured to protect the cable from injury. The small white dots in the centre are the sections of the stranded copper wire through which the electric current flows.

The laying, picking up and repairing of cables involves much ex-



[*By kind permission of Sir Charles Bright.*

FIG. 23.—Sections at various places of a Modern Atlantic Cable. (*a*) and (*b*) are deep-sea portions, and (*d*) and (*e*) the heavily armoured shore ends.

perience. The great cable-making firms, such as the Silvertown Company, Messrs. Siemens Bros., and the Telegraph Construction and Maintenance Company, have their own specially-equipped ships for this purpose. A single repair to a deep-sea submarine cable may cost anything up to £100,000. Great experience as to the best modes of working was gathered by the early pioneers, such as Lord Kelvin, Messrs. Latimer Clark, Varley, and many others, and great improvements have been introduced by their able successors, Dr. Muirhead, Messrs. Herbert Taylor, John Gott, Walter Judd, Raymond-Barker and Rymer-Jones, P. B. Delaney, Pierre Picard, G. O. Squier, S. G. Brown, and many others.

A system of working invented by G. O. Squier involves the use of alternating currents of electricity of low frequency, and has many very

interesting features. It is quite within bounds of possibility that type-printing telegraphs, transmitting hundreds of words per minute, may be actuated through long submarine cables in course of time. Already inventors have made enormous strides towards this end, in proportion as scientific knowledge has increased concerning the principles involved.

We shall next review, shortly, the remarkable invention of the telephone and the associated numerous inventions which have given us that questionable boon of modern life, the Telephone Exchange.

Although several persons had some vague ideas of the possibility of transmitting articulate speech electrically from place to place, the verdict of courts of law, after the most searching inquiry, is that the inventor of the speaking telephone was Alexander Graham Bell. The telephone differs from the telegraph, not only by the fact that it transmits articulate sounds and not merely signals which have to be interpreted, or else printed letters, but in respect of the fact that the telephone is much more the product of a single inventive mind than the telegraph. Alexander Graham Bell was the son of Alexander Melville Bell, who was at one time lecturer on elocution in University College, London. Mr. Bell, senior, went to reside in Canada in 1870, taking his sons with him, and he was the author of a very original treatise on visible speech. Alexander Graham Bell, his celebrated son, had therefore his attention directed to phonetics, acoustics, and music from an early age. Before long an idea arose in his mind of inventing a form of multiple telegraphy which depended upon the electrical transmission of musical tones along a telegraph wire.

His early experiments on this subject led him to a more important conception, viz., that of transmitting electrically along a wire articulate speech.

This, he saw, involved the creation and transmission along a telegraph wire of an undulating electric current, the strength of which should vary just as the air pressure varies at any point in the air when a speech wave passes that point. The question then arose, how to produce such a current by speech and cause it to re-create speech sounds at a distant place. After prolonged experiment Bell arrived at last at the simplest possible solution of this problem. A thin disk of iron was fixed near to the pole of permanent magnet, the polar end near the plate was

surrounded by a coil of insulated wire (see Plate 11, page 70). Exactly similar implements were placed at the two intercommunicating stations and the wires of their magnet coils connected by a double line wire or by a single wire and an earth return. When articulate speech is made against one iron disk the latter is set in vibration by the changing air pressure and this motion creates an induced electric current in the coil wound on the adjacent magnet. This varying current flows through the line wire and strengthens or weakens the magnet pole near the iron disk at the receiving station, and its varying attraction sets in vibration the iron diaphragm and thus reproduces the speech sounds. The beauty of the invention consists in the fact that identical instruments act both as generator of these variable or undulatory currents and also as receiver. They change energy of air vibrations into energy of electric currents, and then effect the reverse transformation and reproduce the air vibrations, and therefore speech, at a distant station.

Bell was the first to effect this transformation. He obtained, in the United States, a patent, No. 174,465, March 7th, 1876, which proved to be a master patent. This patent and the corresponding British patent No. 4765 of December 9th, 1876, had to pass through the fire of much litigation, and a certain disclaimer was made in 1878, but it emerged triumphantly from all the ordeals.

In the year 1876 an international exhibition was held in Philadelphia, U.S.A., called the Centennial, and Bell's telephones were there exhibited in action. Lord Kelvin and Professor Joseph Henry were judges of the electrical exhibit, and Lord Kelvin was immensely enthusiastic over Bell's invention, and expressed himself in a report most eulogistically. He brought away with him to England one form of Bell telephone receiver, and exhibited and described it to Section A of the British Association, which met the same year in August at Glasgow.

The author of this book was present on that occasion and heard Lord Kelvin describe in Section A how he had heard articulate speech transmitted over an electric wire for the first time. He said: "With my ear pressed against this (iron) disk I heard it speak distinctly several sentences first of simple monosyllables, 'To be or not to be' (marvellously distinct). Afterwards sentences from a newspaper 'S.S. *Cox* has

arrived.' I failed to hear the 'S.S. *Cox*,' but the 'has arrived' I heard with perfect distinctness, then 'The Americans in London have made arrangements to celebrate the Fourth of July.' I need scarcely say I was astonished and delighted."

Space will not permit of a full description of the stages by which Bell's telephone came into its final form. In the middle of the year 1877 it consisted of an ebonite tube or handle which contained the bar-shaped permanent magnet. Round the extremity of this was wound a coil of fine insulated wire, and in close proximity to the same polar end was held a thin disk of elastic iron about 2½ inches in diameter, held in place by a mouth or ear piece of ebonite, the section being as in Plate 11, page 70. In other cases a small horse-shoe shaped magnet was employed with its two polar ends both bound with insulated wire. In this form it came ultimately into a shape not much larger than an old fashioned watch. In these steps towards practical perfection Bell was assisted by several friends, whose aid he acknowledged (see Plate 12, page 71).

The result was to give us an instrument of marvellous simplicity and perfection as a telephone receiver. It could also act as a transmitter, but it was not so well adapted for this purpose as other subsequent types. Bell had, however, invented a form of transmitter in which the movement of a diaphragm under the action of the voice was caused to dip a metal pin more or less deeply into a metal cup full of some liquid. By this means the resistance of a circuit including the liquid was caused to vary, and this again to vary the strength of a current in a circuit which included the magnet coils of a receiving telephone. In his specification Bell did not restrict himself to liquids as the variable resistance.

At this stage Mr. T. A. Edison entered the field of telephony as an inventor. He had already paid some attention to the problem of transmitting articulate speech, but Bell's exhibit at the Centennial Exhibition appears to have aroused his interest and he brought at once his great inventive powers to bear upon the problem of producing a telephone transmitter of the variable resistance type. In March, 1878, he applied for a U.S.A. patent (No. 203,016 of 1878), in which he described the use of lampblack as a material in which a sufficient variation of electrical resistance could be brought about by the slight variations of pressure

produced by movements of a diaphragm produced by the speaking voice.

He placed a disk or button of this material between a rigid metal backing and the metal diaphragm against which speech was made, and he included this button in the primary circuit of a small induction coil which also included a few cells of a voltaic battery. The receiving telephone was placed in the secondary circuit of the coil.

Edison's lampblack button did not survive the test of time, but his use of *carbon* as the variable resistance proved of permanent value, and he produced a telephone transmitter of much greater power than the Bell magneto telephone.

The Bell telephone had meanwhile passed into a commercial stage. In May, 1877, the business of renting telephones and erecting lines of communication between pairs of correspondents began in the United States, and it was not long before the idea of a telephone exchange was evolved from previous telegraphic experience, in which a number of subscribers could be put into communication, pair and pair, as they desired.

In March, 1878, Mr. Bell was in England and issued an important memorandum explaining his views on this subject, and before long the practical realisation of his suggestions had begun in the United States. In Great Britain telephone development proceeded more slowly. It was not until the late summer of 1879 that the Bell Telephone Company, of London, was formed to begin the business of exchange telephony, with Mr. Brand as chairman.

Colonel Gouraud, who was Edison's business representative in London, also about the same time registered the Edison Telephone Company of London, with the Rt. Hon. E. P. Bouverie as chairman, and Mr. Arnold White as secretary. These companies started constructing exchanges in London in the autumn of 1879.

The delay in operation was partly due to the patent position. The Edison Company could not at that time use the Bell magneto-receiver, whilst this latter instrument was not powerful enough as a transmitter for exchange working. Mr. Edison, however, promptly took charge of the situation and quickly produced a very novel and effective form of receiver. He had discovered some years previously that the friction between a metal

point and certain substances was reduced when an electric current passed through the point. He therefore fixed on a metal axle which could be slowly rotated by a winch, a chalk cylinder which was kept moist with aqueous solutions of certain salts. On the upper surface of this cylinder a little metal rod rested, which was joined at the other end to the centre of a mica diaphragm. When the cylinder was rotated the friction against the rod was caused to draw back a little the centre of the diaphragm. If, however, speech electric currents from a carbon transmitter are sent across the junction between the metal rod and the moist chalk cylinder a slipping occurs which causes the diaphragm to vibrate so as to reproduce the articulate speech in the form of air waves. This ingenious receiver spoke in very loud tones and was called the Edison Loud-speaking Telephone.

The Edison Company, being, as they thought, free from interference, Edison's scientific representative, Mr. E. H. Johnson, came over with a staff of assistants to put in operation exchange working. The Edison Exchange was established at 11, Queen Victoria Street in London, and subscribers were soon secured.

The Bell Company's first exchange and office was at 36, Coleman Street, London.

It was at this stage that the author became connected with the Edison Telephone Company. Mr. Johnson had to return to the United States for a time, and as a *locum tenens* and temporary scientific adviser the author was appointed to conduct certain pieces of work, through the influence of the secretary of the Edison Company, Mr. Arnold White. Litigation of various kinds loomed darkly on the horizon.

When the telegraphs were taken over by the State in 1870, the Government protected itself by the passage of certain Acts of Parliament in 1868 and 1869, which provided that the business of conducting inter-communications for profit by any means should be a Government monopoly.

The question then at once arose whether a telephone is a telegraph within the meaning of the Acts. The Post Office replied "Yes," and threatened legal proceedings if public telephonic exchanges were established without licence from the department.

Other disputes clouded the skies of telephony, produced by discoveries

and inventions made a year and a half previously by Professor David E. Hughes, the inventor of the printing telegraph, already explained.

Hughes' researches were communicated to the Royal Society of London on May 8th, 1878, and aroused great interest. He found that the Bell magneto telephone was extraordinarily sensitive to small but sudden

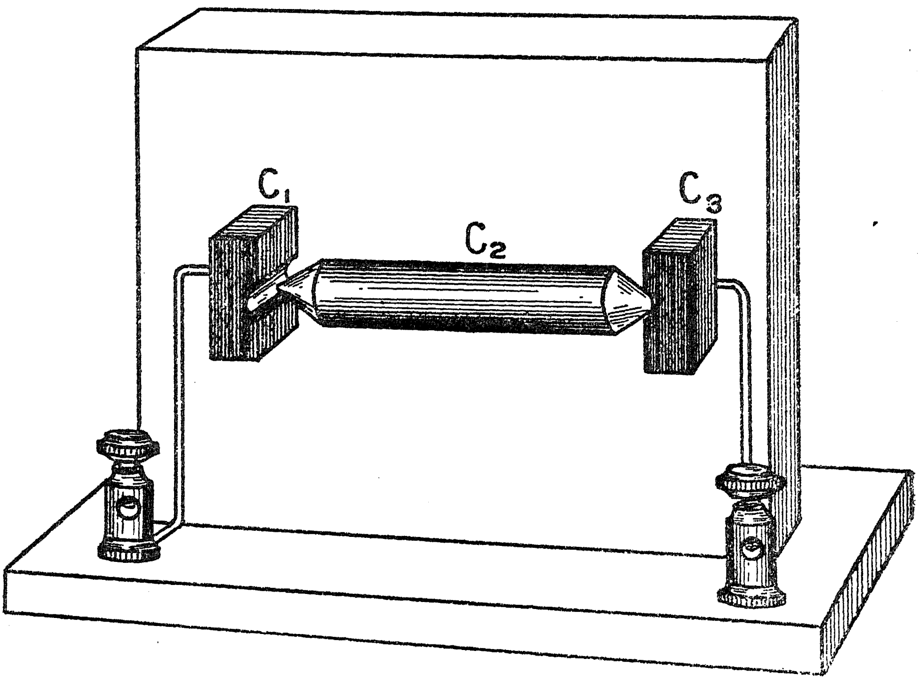


FIG. 24.—One form of Hughes' Microphone. A hard carbon rod C_2, pointed at both ends, rests in grooves cut in two other carbon blocks C_1 C_3. An electric current from a battery is passed through the three blocks and through a Bell telephone. Any small vibrations or sound waves striking against the wood slab on which the carbons are mounted makes the middle carbon jump, and the varying electric resistance at the loose contacts causes a sound in the telephone due to fluctuations in the current through it.

changes in the current flowing through it. He joined a few cells of a battery in series with a Bell telephone, and found that if the circuit contained anywhere a loose contact, such as would be obtained by cutting the copper wire of the circuit and laying the ends lightly across each other, very minute changes in pressure at this loose contact caused variations in the current, which again created loud sounds on the telephone.

A very sensitive loose contact was formed by laying a small light bar of graphitic carbon across two other blocks of the same material, which were connected to the ends of a circuit made by placing a Bell telephone in series with two or three cells of Leclanché's battery (Fig. 24). If these blocks were mounted upon a wooden base, it was found that very slight vibrations made a loud sound in the telephone. Thus, placing a watch on the wood slab, its ticks made loud sounds on the telephone. Hughes thought that this instrument enabled faint sounds to be magnified and he called the arrangement a *microphone*. A favourite experiment at that time was to enclose a house fly in an empty match box and place the box near the microphone. It was said that the sound of the fly's footsteps walking in the box could be heard in the telephone like the tramp of an elephant. The sounds were often heard when the fly had escaped or was lying dead in the box, and they were really due to small vibrations arising from some cause which made the middle carbon rod shake, and so varied the resistance of the loose contacts and, therefore, the current through the telephone.

Hughes' experiments, however, threw a flood of light on many phenomena of electrical contact resistance, and they led to the invention of many forms of microphone transmitter for telephony. They aroused also a vigorous controversy with Mr. Edison, who considered that his ideas and invention had been appropriated. Some of the phrases used by Edison in his specifications imply that he was well aware that change of intimacy of *surface* contact would change resistance. In other cases, like that of the lampblack button, he seemed to make use of compression on the mass or more intimate contact of the particles composing the mass than of mere surface contact.

Emile Berliner in 1877 had made use of a microphonic or loose contact between metals to construct a telephone transmitter, but whatever the prior use of such loose contacts may have been, Hughes' researches made a new point of departure, and several new carbon transmitters appeared, such as those of Blake, Hunnings and Gower, which were claimed to have been based on Hughes' researches and to be outside Edison's patent.* In view of all these disputes the Bell and Edison Telephone Companies

* See *The Telephone and Telephone Exchanges*, by Mr. J. E. Kingsbury, Chapter XI.

found it to their interest to amalgamate early in 1880 and combine together to resist their common foe, viz., the General Post Office, which claimed under the Telegraph Acts to control all public telephony. The important case of *The Attorney-General* v. *The Edison Telephone Company of London, Ltd.*, was heard by Mr. Justice Stephen and Baron Pollock in 1880. The scientific witnesses for the Crown were Mr. (afterwards Sir) W. H. Preece, Sir Charles Bright, Messrs. W. H. Barlow, Latimer Clark,

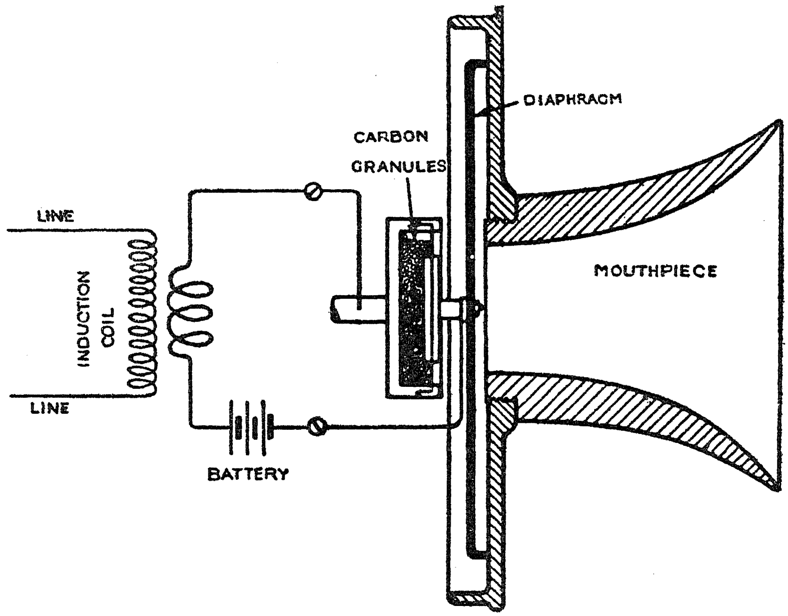


FIG. 25.—Section of the Solid-back Telephone Transmitter now used in British Post Office Telephone Exchange System.

D. E. Hughes, and Warren de la Rue. The Telephone Company retained Lord Rayleigh, Sir W. Thomson (Lord Kelvin), Sir G. G. Stokes, Professor Tyndall, Dr. J. Hopkinson and Dr. J. A. Fleming. In spite of the arguments that the Government acquired merely the telegraphs as then known in 1870, and not every possible means of communication which the wit of man throughout the future ages might invent, the judges gave their judgment in favour of the Crown. The case, unfortunately, never went to appeal. The Post Office offered a licence to the telephone

companies in return for a royalty of 10 per cent. on their receipts, and the terms were accepted.

The long story of the subsequent relations of the Post Office and the telephone cannot be related here in detail, but the reader will find all possible information given in the work of Mr. J. E. Kingsbury, entitled *The Telephone and Telephone Exchanges* (Longmans, Green & Co., London), Chapter XXXII.* Suffice it to say, that after innumerable changes and amalgamations, the business of exchange telephony came to be conducted exclusively in Great Britain by a single corporation called The National Telephone Company, but the Government erected and owned the trunk lines and, finally, in 1911, the whole business was taken over by the Government, as were the telegraphs in 1870.

By that time the permanently adopted types of receiver and transmitter were the Bell magneto-telephone and a carbon transmitter of microphone type, consisting of a very shallow box containing granules of graphitic carbon.† These were pressed by a metal disk attached to the back of the diaphragm, against which speech was made, and the greater or less compression of the carbon granules varied the resistance of a circuit which contained also the primary circuit of an induction coil, and a source of electromotive force, such as a battery (see Fig. 25). The secondary circuit of this induction coil was connected to the line wires and these again to the terminals of the coil of the magneto-receiver (see Fig. 26). In the early stages of exchange working, each subscriber had his own battery, generally two or three Leclanché cells, which also supplied the means of ringing up the exchange operator to obtain a desired connection.

As subscribers increased the problem of the switchboard had to be faced. As long as subscribers were few, it was sufficient to bring each supply line to a pair of terminal blocks on a board, and these were joined across by plugs and flexible conductors as required, but as soon as subscribers began to multiply these simple contrivances were found quite inefficient and, even in 1879, at some exchanges great difficulties arose

* See also *The Times*, July 15th, 16th, 17th, 19th, 20th, 21st, 22nd, 23rd, of 1920, for a series of able articles on this subject.

† This design, called a solid-back transmitter, was due to Mr. A. C. White, patented in 1892.

owing to the multiplication of subscribers. It was soon found that one exchange operator could not deal with calls from more than fifty subscribers, at most, and that it was not practicable to have several operators at one board.

Hence arose the idea of a "multiple switchboard," in which each subscriber's line terminated at several switchboards, each of which was controlled by an operator. But this involved another difficulty, viz., for each operator to determine whether a subscriber's line was engaged at another board or free for a cross connection. It would be impossible to

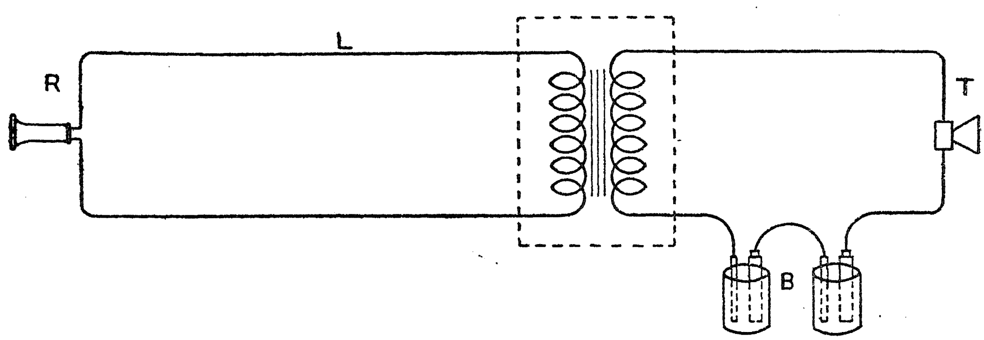


FIG. 26.—General Scheme of Apparatus in a Telephone Circuit. B is a battery; T is the transmitter; R the telephone receiver; L is the line wire. When speech is made to the transmitter T the variations in compression of its carbon granules vary the current sent by the battery B through the primary coil of the induction coil, and this, in turn, creates another electric current in the secondary coil which flows through the receiver. The two spirals enclosed in a dotted line denote the induction coil.

detail here the stages of elaborate inventions by many able telephonists by which we have reached the modern multiple switchboard. It occupies a very interesting chapter in the valuable book by Mr. Kingsbury on the telephone and telephone exchanges. Suffice it to say, that in present exchanges worked by human operators, each subscriber's line termination is branched to a large number of panels, and groups of these panels are under the care of an operator, generally a girl (see Plate 16).

Before entering into details it may be well to explain that in 1891 or 1892 Mr. H. V. Hayes, in the United States, patented and described an extremely important improvement in exchange working called the common battery (C.B.) system of working. The numerous separate

transmitter batteries in each subscriber's set, which had always given enormous trouble, were removed and their place taken by one battery of large storage cells placed in the exchange. In the next few years this system was gradually improved in the United States, and finally adopted

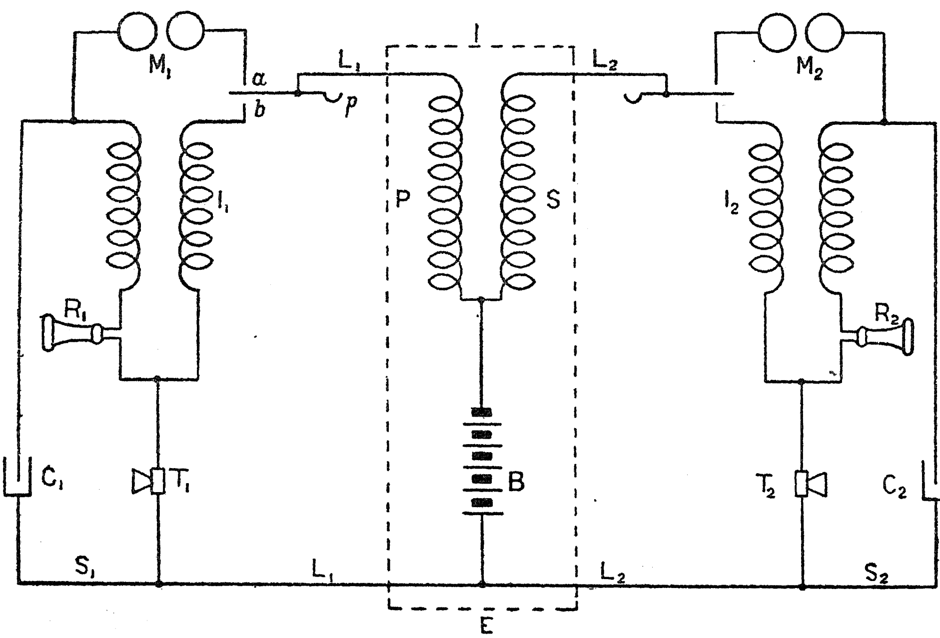


FIG. 27.—Scheme of Circuits of the Common Battery (C.B.) System of working a Telephone Exchange. B is the common battery situated at the exchange, which is denoted by the dotted enclosure. On the right and left are two subscribers' telephone sets. L_1 and L_2 are their lines to the exchange; M_1 M_2 are their call bells; R_1 and R_2 their receivers; and T_1 and T_2 their transmitters; and C_1 and C_2 their condensers. Their receivers normally hang on the hooks *p*, but when lifted off make a connection which calls up the exchange.

by the National Telephone Company in 1900 and by the General Post Office in 1902.

A feature of this system is that all the subscribers draw the supply of current for their transmitters from a common battery B, and this current on its way passes through a relay which lights up a small incandescent lamp on the exchange switchboard (see Fig. 27). The apparatus installed with the subscriber is only a receiving telephone, a carbon microphone transmitter, a call bell, and a condenser (see Plate 15). The call bell is

operated by an alternating current sent out from the exchange, and when the subscriber is not using his telephone the receiver hangs on a hook by the transmitter and the connection is so made that the bell rings if the exchange sends out an alternating current. When the subscriber takes his receiver off the hook this act automatically disconnects the bell and a direct current from the battery passes through the subscriber's transmitter, and also lights up the corresponding small electric lamp at the exchange, and thus calls the attention of the operator to the fact that a subscriber is either making a call or is ready to answer one. The moment the subscriber puts his receiver back on the hook the signal lamp goes out.

Returning now to the structure of the multiple switchboard at the exchange. This consists of a number of upright panels with a desk or table in front and at each panel a girl sits (see Plate 16). To a lower part of the panel the terminations of a certain number of subscribers' lines, say 200, are brought; above these are panels which contain the terminals of all the subscribers or connections to the exchange, and these last are repeated on each operator's board and joined in parallel. Hence a subscriber's line terminates at several such boards. When a subscriber makes a call the girl connects her own operator's telephone with his line by means of a plug connection and asks the number of the subscriber he wants. Before connecting the caller with the required subscriber the girl has first to ascertain whether the latter is already engaged. This is done in the following manner: Each line terminates on all the sets of panels of the multiple board in a pair of spring clips called a "jack," and these jacks are fixed to the back of the board. A plug or peg can be put through a hole in the board which is lined with a metal collar, and this brings a pair of insulated wires in a flexible cord attached to the plug into electrical connection with that circuit.

When a plug is inserted into a hole the metal collar is also brought into electrical connection with one side of the battery circuit, so that it is in condition to send a current through a receiving telephone connected to it. Accordingly, every collar on the multiple board belonging to that subscriber is electrified by the act of putting in a plug into one of the multiple jacks belonging to him on any of the panels.

We can now follow out in detail the operations of a "call." Let us suppose that subscriber No. 150 wants subscriber 700. The moment No. 150 takes his receiving telephone off the hook the corresponding electric lamp lights up on the panel (say No. 1). The girl then plugs her own telephone into his circuit and asks what number he requires. On hearing from him that he wants No. 700 she looks out on the upper panel of the multiple board the jack of No. 700, and she touches the collar with the tip of the plug of her own telephone. If No. 700 is already engaged she hears a "tick" in her own telephone, which warns her not to push the plug home. She therefore connects the calling subscriber with a device called a "busy back," which creates a buzzing sound in his receiver, and this warns him that the line required is engaged. If, on the contrary, she hears no "tick" when touching the jack of No. 700 with the tip of the plug she pushes the plug in and connects the circuit to a machine giving an alternating or rapidly reversed current of electricity which "rings up" the wanted subscriber. The moment she sees his indicator lamp light up she knows he has taken his receiver off the hook and is ready to hear.

She then interconnects the jacks of caller No. 150 and that of the called circuit No. 700, by means of a flexible pair of wires with plugs at each end and leaves the two subscribers to converse.

As soon as they finish their conversation and put back their receivers on the hooks, their indicator lamps at the exchange go out and the girl removes the plugs and turns her attention to other calls.

On a large exchange the majority of calls are for subscribers whose lines terminate on jacks out of reach of a single operator or for subscribers on other exchanges, and this necessitates cross connections of a more complicated kind. The above description will be sufficient, however, to show the general nature of the operations which have to be conducted at the exchange to "get through" from one subscriber to another.

At a very early stage in public telephony inventors began to nourish the hope of eliminating the human element altogether from exchange working, with its trying strain on the nervous system of the telephone girl and tax on the subscriber's patience. By slow degrees the main principles of an automatic exchange were evolved and the details gradually perfected,

until to-day automatic or machine exchanges are coming into extensive use.

The full details of an automatic exchange are not easy to describe without the aid of many elaborate diagrams, but the broad principles may be understood by considering a very simple case. Let us suppose an exchange which possesses only 100 subscribers, and that it is desired to make arrangements by which any subscriber can automatically put himself into connection with any other. Suppose that at the exchange there is a certain kind of switch called a Strowger switch from the inventor who first introduced a particular form of it (see Fig. 28 and Plate 15, page 88). Let there be a hollow cylinder or semi-cylinder of insulating material on the inner surface of which there are pairs of metal blocks, which are the terminals of subscribers' lines, arranged in ten rows and ten columns. Let there be a double radial arm of metal which turns on an axis concentric with that of the cylinder, and can be turned round so as to make contact with the blocks in any row or raised or lowered so as to make contact with blocks in any column. Let this double radial arm be in connection with some subscriber's line. By means of electro-magnets it is possible for the calling subscriber to actuate this switch and place his own line in connection with that of any other subscriber. The mechanism by which he does that is as follows: On his table telephone there is a little dial having the nine digits and zero engraved on its edge, and there is a little radial arm which the caller can push round to any position and then let go (see Plates 17 and 18, page 89). If, for instance, he requires No. 78, he pulls the radial arm round to face No. 7 on the dial, and then lets it spring back. In so doing it sends to the exchange seven brief electric currents. He then repeats the process, pulling over to No. 8, and this sends out eight brief currents. These currents are then made to actuate a device called a Register which stores up the number called and in turn operates the selector switches to make

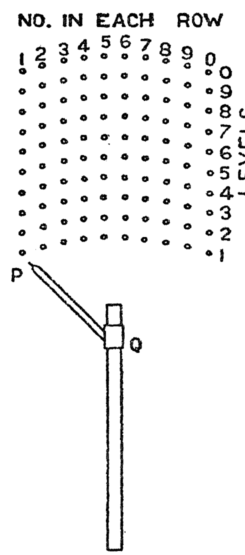


FIG. 28.—Simple Sketch of the Arrangements of a Strowger Switch.

the connection. The first seven impulses sent raise the radial arm level with the seventh row of blocks, and the succeeding eight impulses turn the arm to the eighth block on that row and put the subscriber in connection with subscriber No. 78. But now there are many other problems involved. The first question is as to the maximum number of subscribers which may require to intercommunicate at any one moment. It is clear that if all subscribers require so to do at once each would have to possess his own selector switch at the exchange, and this would introduce an almost impracticable complication.

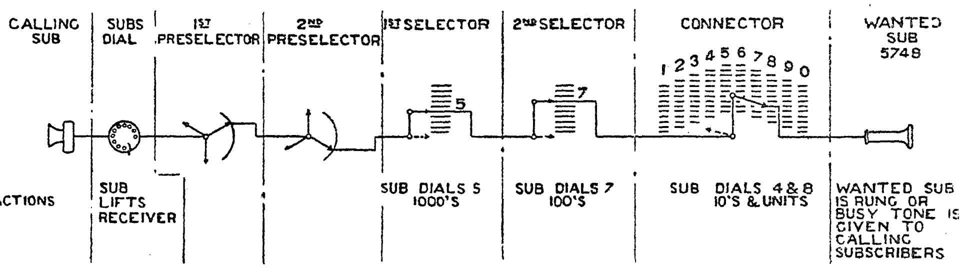
But experience shows that in a large exchange, even at the busy hours, not much more than one-tenth of the whole number are desirous of intercommunicating at the same instant. Hence it suffices to provide for a certain number, say, 10 per cent. of the whole number of subscribers, of selector switches to give an opportunity to any subscriber to make a call. We have then to add a mechanism by which a calling subscriber can possess himself of a selector switch or switches. This process is called "trunk hunting." In the next place we have to furnish a mechanism which shall prevent a subscriber from connecting himself to a line already engaged with a third user, and which must warn the calling subscriber that the line he wants is already being used by another. The manner in which this is done is somewhat as follows:—When the calling subscriber operates his own number-sending dial, the feeble electric impulses he sends out by it actuate a mechanism called a Register, which stores up the complete number, and this sends out again at the proper moment stronger electric currents, which control the selector and connector switches (see Plate 18, page 89). These latter are massive constructions, in which the radial arms are turned by electric motors continually in operation, and the controlling electric impulses merely set in operation a clutch, which applies the motive power just as the slight pressure of the foot on a pedal applies or releases the engine power in the case of a motor-car.

In the case of large exchanges, having, say, 10,000 subscribers, switches have to be worked in series, the first finding the thousands and hundreds in the required number, and the second the tens and units. Thus, to connect to No. 6,876 the first switch, having ten row and ten column

blocks, would be put to touch the sixth row and eighth block, which gives 6,800, and this would connect to a second switch, which would connect to the seventh row and sixth block, and thus connect to the required number.

The electrical arrangements are such that only one subscriber can use one switch or pair of tandem switches at the same time, and also at any other free set of switches the access to a line in use by one subscriber is blocked for all other callers, so that by no means can two callers succeed in interfering with each other by connecting to the same called subscriber.

The manner in which a subscriber puts himself through to another

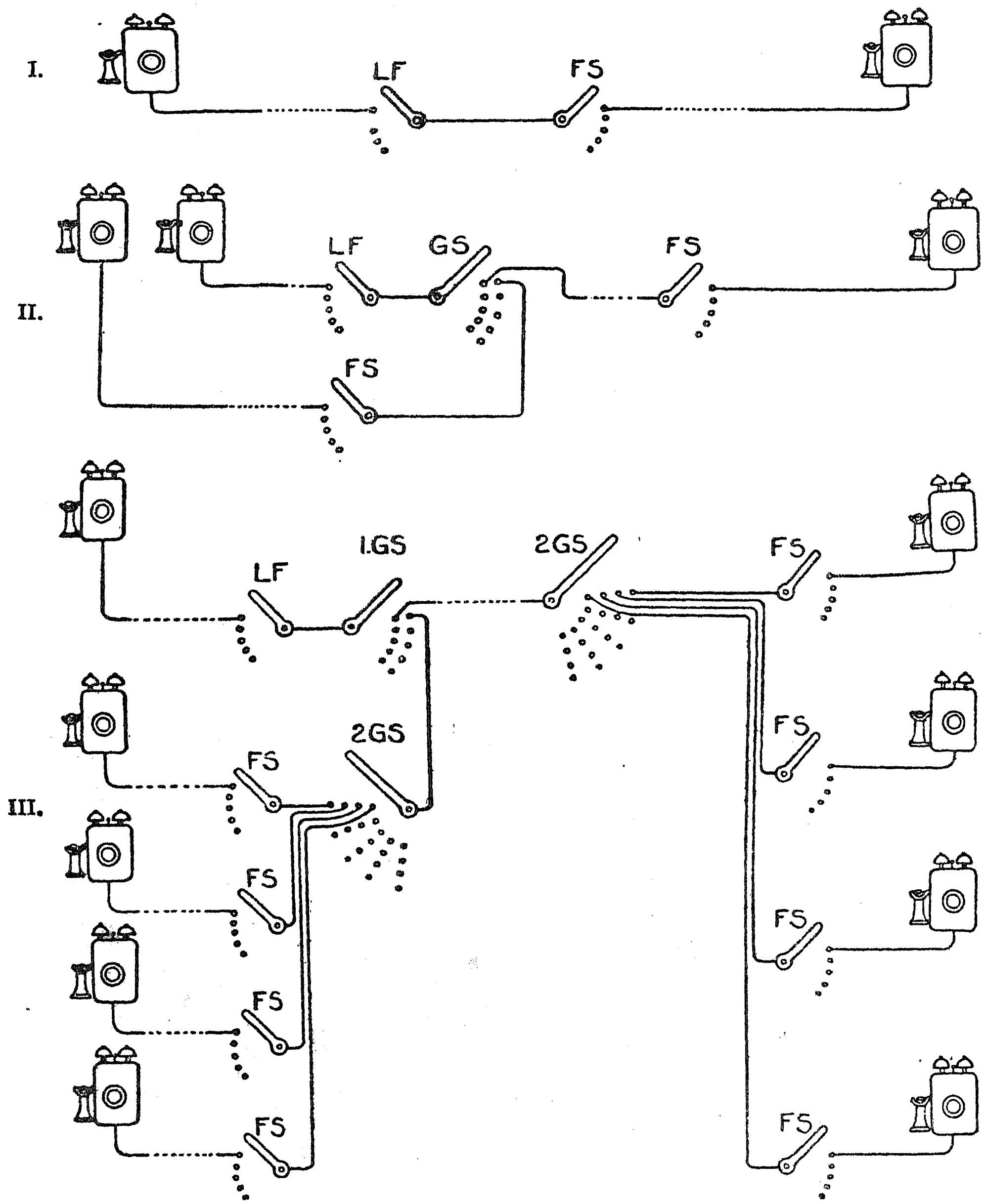


[*Courtesy of " Conquest."*

FIG. 29.—Outline Arrangement of the Chain of Selector and Connector Switches required in an Automatic Telephone Exchange to enable a calling Subscriber to put himself through to any other Subscriber.

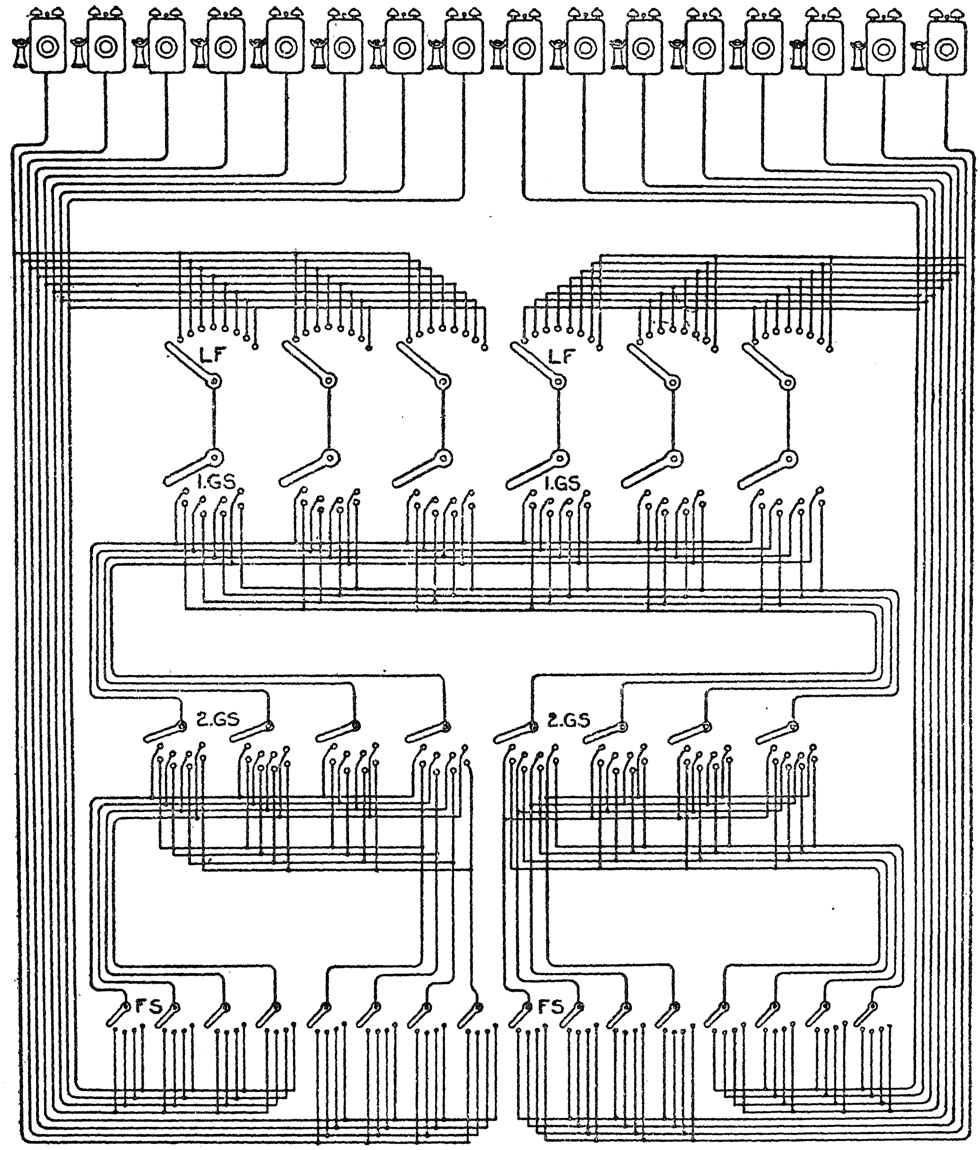
wanted subscriber by a series of switches which are operated by electric power at the exchange may perhaps be understood from the outline diagrams in Figs. 29, 30 and 31. The electric impulses sent out when the calling dial is operated act through relays which in turn actuate the selector and connector switches at the exchange.

The details of all these contrivances are very complicated, but they have been worked out in full by several corporations and firms which now provide the equipment for automatic telephone exchanges, such as the Automatic Telephone Manufacturing Company, supplying Strowger type apparatus (A); the Western Electric Company, supplying a motor-driven continuous-drive apparatus (W); Messrs. Siemens Brothers (S), and the Canadian Machine Telephone Company, supplying the Lorimer System (L). All these systems have been tested and put in operation by the British General Post Office.



[*By permission of the Western Electric Co.*

FIG. 30.—Diagrams representing in Outline the Mode of connecting Subscribers in an Automatic Telephone Exchange by Line Finder Switches (L.F.), Group Switches (G.S.), and Final Switches (F.S.) on the Western Electric Company's System. The studs (small circles) on the L.F. switches are the terminals of subscribers' lines. The group switches, 1 G.S. and 2 G.S., serve to interconnect various groups of subscribers, and the final switches (F.S.) find the wanted subscriber.



[By *permission of the Western Electric Co.*

FIG. 31.—Diagrammatic Arrangement of Switches and Subscribers in an Automatic Telephone Exchange serving to inter-connect the Subscribers pair and pair.

The announcement has been made (July, 1920) that a beginning is to be made with automatic exchanges in the City of London, where one will be equipped for 3,000—4,000 lines on the Panel Selector system of the Western Electric Company. Also, an exchange at Fleetwood (Lancs.), for 1,000 lines, is to be equipped with the Relay Automatic Company's plant. There will thus be six types of plant for automatic exchange telephones in operation under the criticism of the G.P.O. Fig. 54 shows a view of part of an automatic telephone exchange on the Panel Selector system of the Western Electric Company, Ltd., about to be installed in the City of London (see Plate 19, page 102).

A partial list of the twenty automatic exchanges erected by the G.P.O. up to 1921 is as given below :—

Exchange.	System.	Capacity. Present.	Capacity. Ultimate.	Date opened.
Accrington	A	700 lines	1,500 lines	March, 1915.
Blackburn	A	2,200	4,400	October, 1916.
Chepstow	A	65	90	July, 1915.
Dudley	W	500	1,600	September, 1916.
Darlington	W	800	2,600	October, 1914.
Epsom	A	500	1,500	May, 1912.
Grimsby	S	1,300	4,000	
Hereford	L	500	900	August, 1914.
Leeds	A	6,800	15,000	
Newport	A	1,800	3,500	August, 1915.
Paisley	A	1,100	2,150	July, 1916.
Portsmouth	A	5,000	7,000	April, 1916.
Stockport	S	950	2,260	

In addition to these complete automatic exchanges there are exchanges worked on the semi-automatic system, which do not entirely dispense with human directive agency, but in which that element is aided by a certain amount of machine selection.

Taking the automatic system, however, in its completeness, we may say that this immensely ingenious mechanism is the nearest approach the human mind has yet made to the construction of an artificial brain, with its ganglion switches, copper wire nerves, electric current circulation,

and electromagnetic muscles, all controlled by an unseen intelligence, viz., the distant subscriber, who is able to give the number of another subscriber, find out if he is already engaged or free, put himself in connection with him if free, carry on a telephonic conversation, and then cut himself off from connection—all by means of mechanism controlled by himself by feeble electric impulses he sends out at will from his room or office. Truly, this seems the very high-water mark of human creative power.

We must, then, briefly consider the improvements made of late years

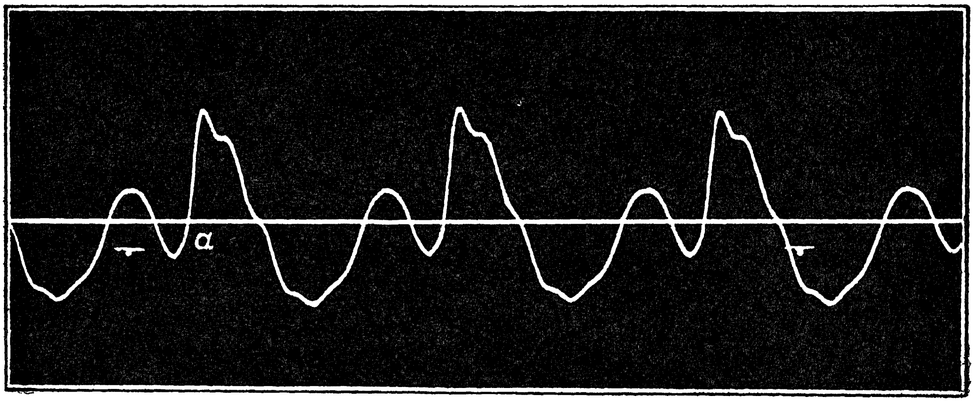


FIG. 32.—A Line representing the Wave Form of a certain Musical Sound. The distance of any point on the line above or below the horizontal line represents the degree of compression or rarefaction of the air at any fixed point in space at that instant.

in extending the range of telephony on land lines and through submarine cables.

It will be necessary to give first a few explanations as to the nature of articulate speech.

Outside of ourselves, and considered merely from a physical point of view, sound consists in vibrations taking place in the air. In these vibrations the air particles move to and fro through very minute distances with a pendulum-like motion in the direction in which the sound is travelling. If a sudden explosion is made, for instance, at some point, the result is to push the air outwards, but, on account of the compressibility and inertia of the air, the result is to make a spherical layer or shell of

compressed air. This at once expands and compresses the air beyond it, and so a spherical shell of compressed air is formed which expands outwards. The region of compression moves with a velocity of about 1,100 feet per second, but each air particle only moves forward a little way, perhaps not a millionth of an inch, and then falls back.

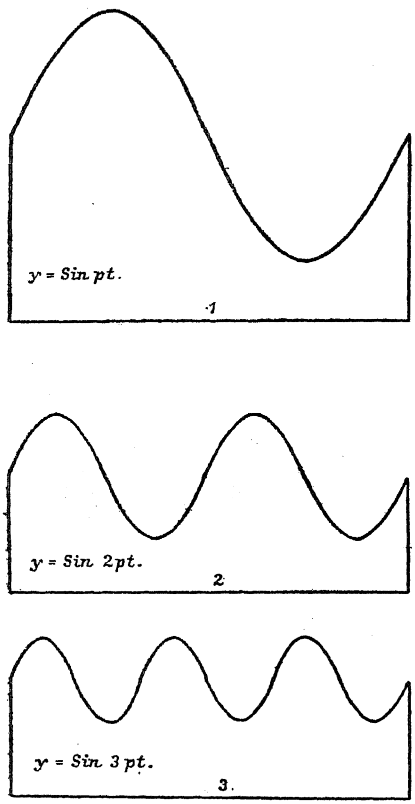


FIG. 33.—Simple Harmonic Curves of various Wavelengths and Amplitudes.

Suppose, however, that the sound is a sustained musical note; then a series of shells or zones of compression, followed by shells or zones of rarefaction, move outwards, and each air particle oscillates in a radial direction with pendulum-like motion. The distance from one zone of compression to the next is called a wave-length. The number of times per second an air particle completes a cycle of movements is called the *frequency*.

The frequency multiplied by the wave-length is numerically equal to the wave velocity, namely, 1,100 feet per second.

We can represent the movement of the air particle by a wavy line, as follows:—Let time be marked off in any suitable scale along a horizontal line, and let the displacement of the air particle be represented to some other scale by lines drawn upwards or downwards at right angles to the time line. Then, if we join the tips of all these upright lines, we have a wavy curve, called the wave form of the sound (see Fig. 32).

In the case of a pure musical sound this curve is a regular curve, called a simple harmonic curve (see Fig. 33); but in the case of an impure sound or speech it is an irregular curve (see Plate 20, page 103, upper diagram).

There is a remarkable theorem, due to a great French mathematician,

Fourier, which tells us that any such irregular curve as in Fig. 34 can be constructed by adding together the ordinates or heights, corresponding to the same point on the base line, of a certain number of simple harmonic

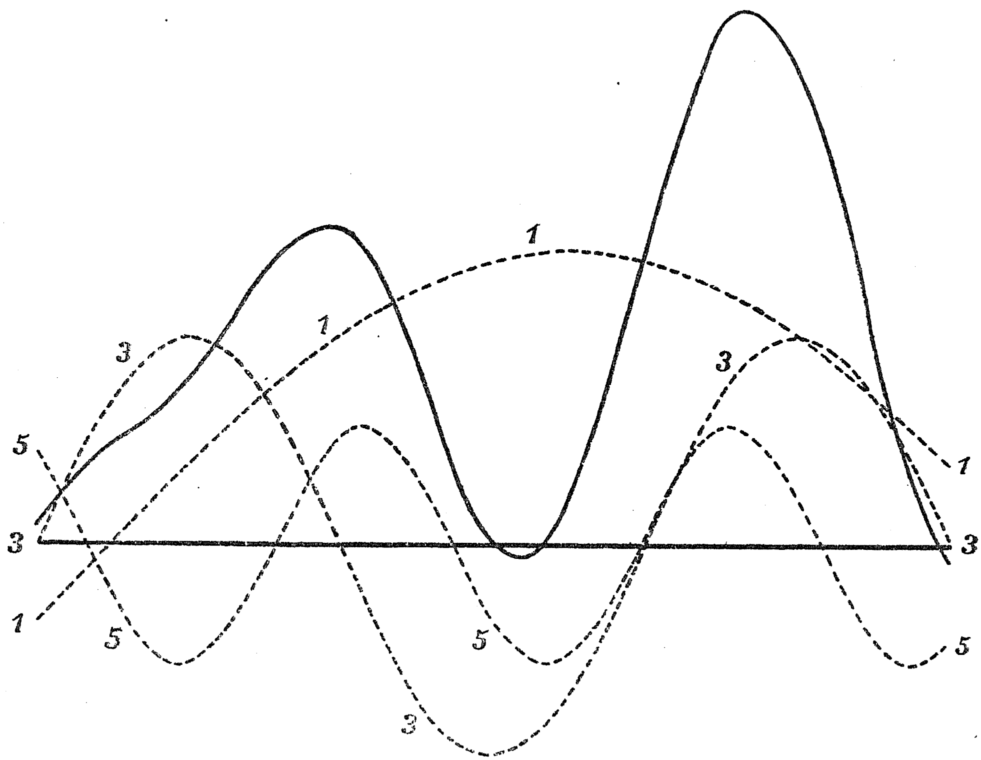


FIG. 34.—Diagram illustrating Fourier's Theorem. The firm black-line curve is a complex periodic curve, and its ordinates, or the height of any point on it above the horizontal datum line, can be shown to be equal to the sum of the ordinates at the same point of those of the simple harmonic curves 1, 3, 5, whose wavelengths are in the ratio of 1, $\frac{1}{3}$, $\frac{1}{5}$, and amplitudes in a certain ratio.

curves suitably placed whose wavelengths are in the ratio of $1 : \frac{1}{2} : \frac{1}{3}$, etc. (see Fig. 34), and amplitudes have a certain magnitude.

If we translate this into acoustics it means that any complex sound like a vowel sound, ah, oh, oo, etc., can be reproduced by making simultaneously simple sounds, such as those made by tuning forks, which have frequencies in the ratio of 1 : 2 : 3, etc., and each a certain adjusted loudness. The longest wave of the set is called the *fundamental* wave,

and the others are called the *harmonic* waves. The wave form is, therefore, built up of a fundamental curve and a set of harmonic curves, each having a certain *amplitude* or maximum height and placed in a certain relative *phase* or position with regard to each other.

All spoken language consists of certain vowel sounds, which are continuous sounds capable of being uttered as long as breath lasts, and also certain consonantal sounds which for the most part are merely abrupt beginnings or endings to vowel sounds (see Fig. 35).

The vowel sounds have not only a certain loudness, but a certain *quality* or character which distinguishes them from each other. The loudness depends upon the amplitude of the motion of the air particle or of the wave-form curve which represents it. The quality depends on the shape of the wave-form curve, and this again upon the kind and number of harmonics present in that sound. In telephonic transmission we speak to the transmitter and cause certain very irregular changes in air pressure against the diaphragm or disk of the transmitter. As already explained, the vibrations of this disk make corresponding changes in the strength of an electric current flowing in the line wire. These again actuate the receiver and make corresponding movements of its diaphragm, and these finally recreate at the receiving end aerial vibrations of the same, or approximately the same, wave form as those of the speech made to the transmitter. In this very complex process there are several transformations of energy, but in order that intelligible speech may be transmitted it is essential that there shall be at the receiving end a certain loudness of sound and a certain approximate reproduction of wave form. This necessitates that the various harmonic constituents in the current wave which go to make up that wave form shall be transmitted at the same speed and all attenuated or weakened in the same proportion by the line, or else the received wave is a mere caricature or burlesque of the transmitted wave.

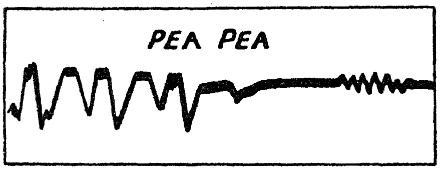
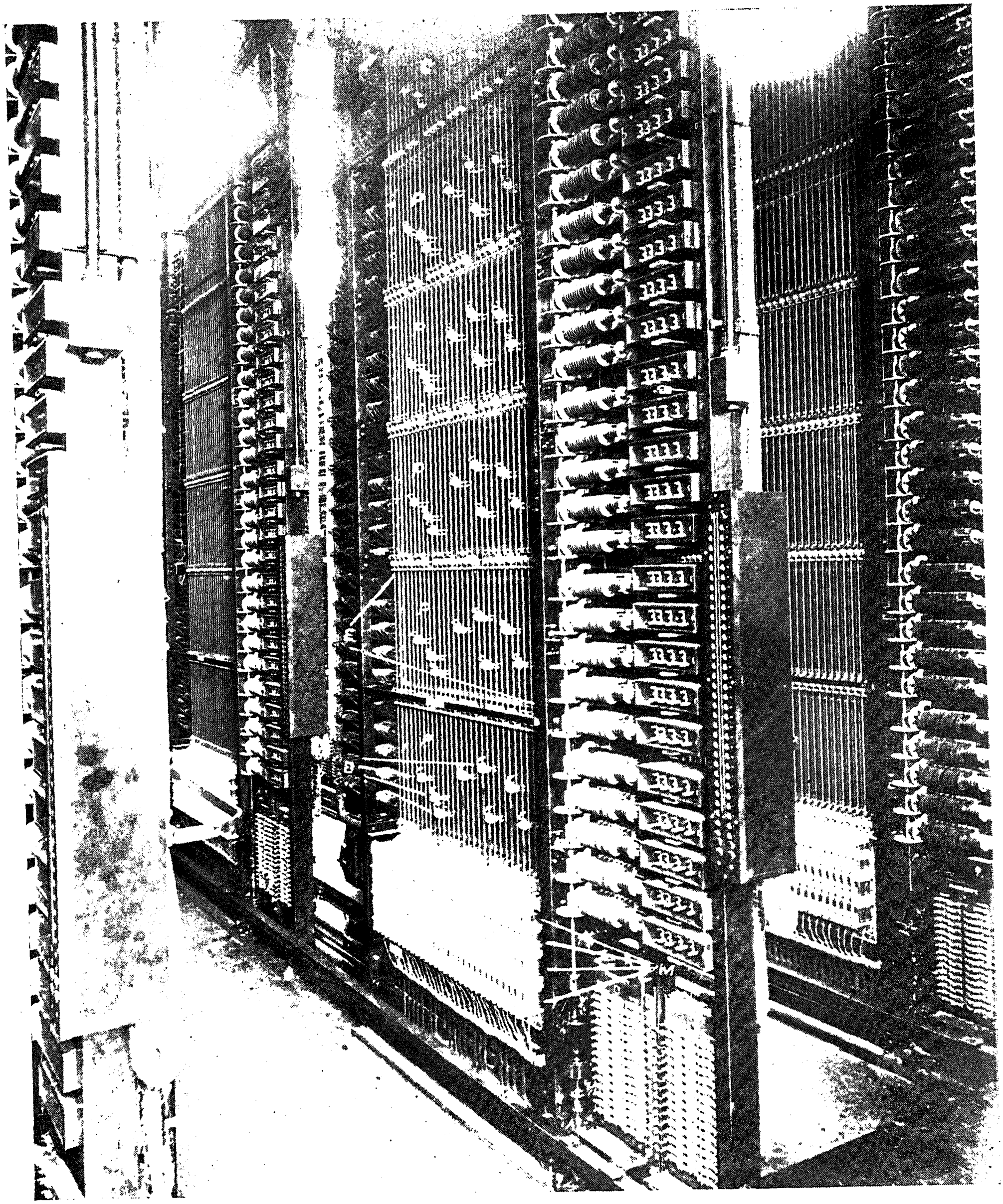


FIG. 35.—Graphic Representation of the Wave Form of a Speech Sound. The little ripples on the right correspond to the explosive sound of the letter P, and the larger irregular waves on the left to the EE sound which follows.

PLATE 19.



A View of Part of the Interior of an Automatic Telephone Exchange on the Panel Selector System of the Western Electric Company, Ltd. Vertical racks are used instead of semi-cylindrical contact switches.

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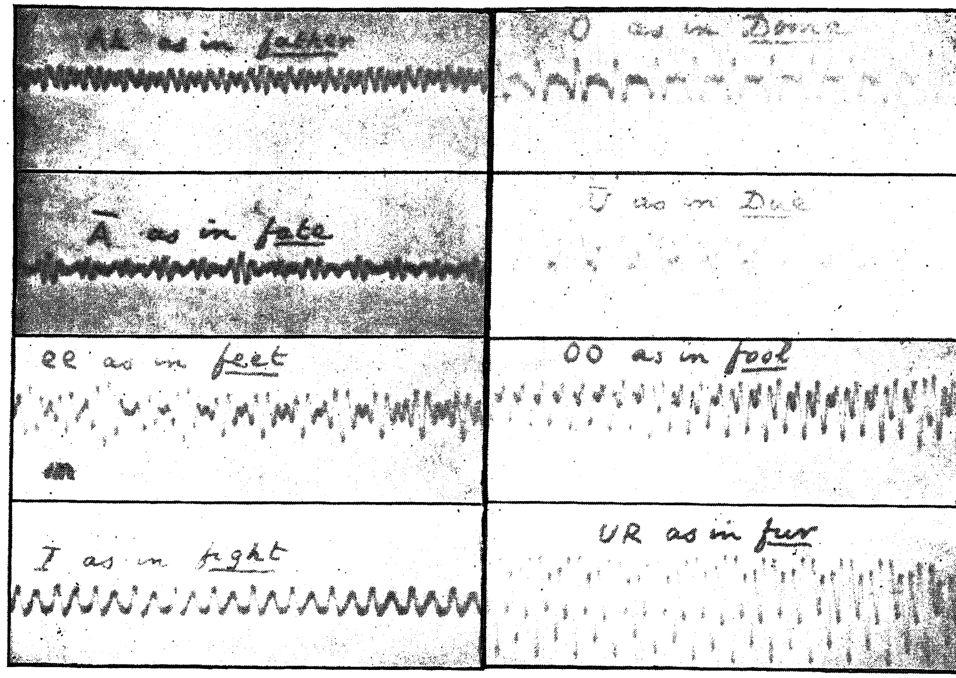
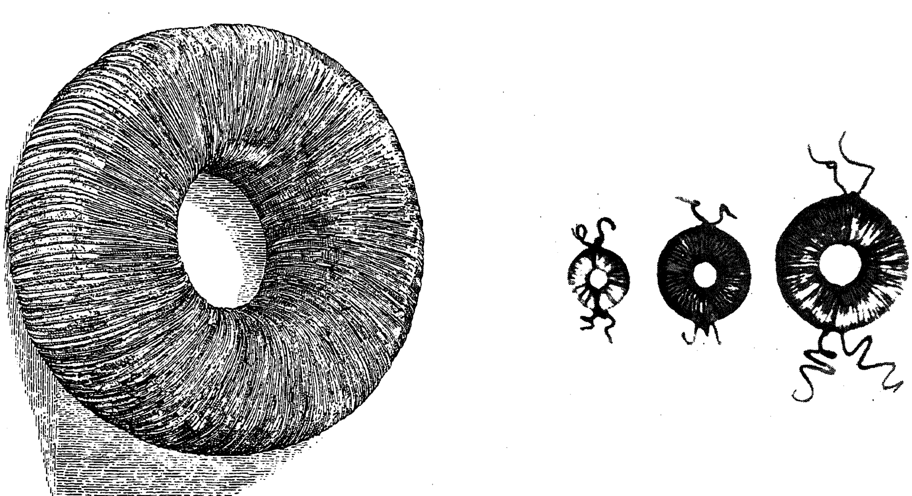


Curves representing the Wave Forms of certain Vowel Sounds, photographed on kinema films by the Fleming Phonoscope.



Loading or Inductance Coils inserted in the run of a Telephone Cable. The coils are made by winding two silk-covered copper wires in many turns on an iron wire core shaped like a lifebuoy. The function of them is to cure the distortion of the wave form of the electric currents travelling along the cable, as explained on page 103.

[*To face page* 103.

It so happens, unfortunately, that the electric waves of different wavelengths do not travel at the same speed along a cable and are not equally weakened. The shorter waves travel fastest and are most rapidly weakened. Hence, the wave form is *distorted* by the line or cable, and beyond a certain limited distance this distortion deprives the articulate sound of all quality or character which gives it meaning (see Figs. 36

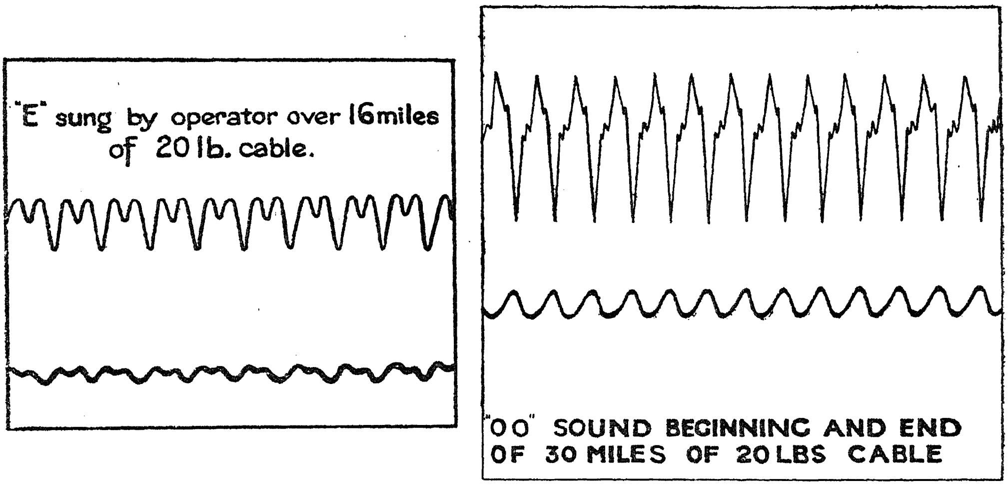


FIG. 36.—Curves showing the Distortion of the Wave Form of a Speech Sound in travelling along a Telephone Cable. The upper curves represent the form at the sending and the lower at the receiving end. It will be noticed that the little irregularities which give the sound *quality* are removed on the journey.

and 37). The problem then presented to electricians in the early days of telephony was : How to prevent or cure this wave-distortion ?

One way is to put more copper into the line or cable and so reduce its resistance, but this is an heroic remedy which is generally too costly. A second method is to reduce the electrical capacity of the line or its power of taking up electric charge. This depends very much on the nature of the material with which the cable is insulated or on the so-called specific inductive capacity of the insulator. Unfortunately, gutta-percha, which is the only material suitable for insulating submarine cables, has rather a large specific inductive capacity, but dry paper has a much less capacity. Hence, it was found advantageous to insulate telephone wires

for underground work, by twisting round them strips of dry paper and then twisting together pairs of these wires to make a circuit (lead and return), and then twisting many pairs and enclosing the whole in a perfectly watertight lead sheath or pipe. Such a cable is called a *dry core multiple twin* cable, and has proved a great advance in improving telephony. Nevertheless, there is a further remedy for distortion, which was strongly urged by an eminent mathematician, Mr. Oliver Heaviside, thirty-five years ago, and that is to increase the *inductance* of the line. Every electric circuit possesses a quality resembling the mass or inertia of matter, in virtue of which changes in current-strength cannot be made

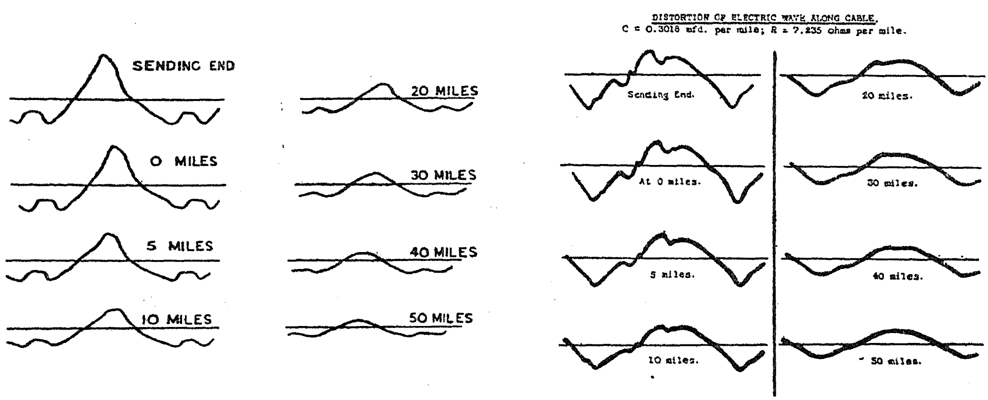


FIG. 37.—Distortion of the Wave Form of a Speech Current in travelling along a Telephone Cable fifty miles in length. It will be noticed that the distortion increases with the distance travelled.

suddenly, just as changes in speed cannot be made suddenly in heavy masses.

We can bestow increased inductance on a wire by wrapping it round spirally over its whole length with thin iron wire, or else by inserting in the circuit at intervals coils of insulated copper wire wound spirally round a bundle of fine iron wire. This process is called *loading* the line. The first method is described as *uniform loading* and the second as *coil-loading* (see Fig. 38). In spite of Mr. Heaviside's repeated insistence on the advantages of loading, British official telegraphists paid no attention to his advice until Professor I. Pupin in the United States investigated the best conditions for coil loading in 1899 and 1900. He showed that to be effective the loading

coils must be spaced on the line, so that at least nine or ten coils occupied the length of one wave of current. This generally means that on underground lines they must be about two miles apart, on aerial lines about eight to twelve miles, and on submarine cables about one mile. The coils used for this Pupin loading are made with cores of fine iron wire rolled up into a ring, and overwound spirally with two coils of insulated copper wire (see Plate 20, page 99). These coils are inserted in the lead and return of the line. In aerial lines the coils are put in iron boxes attached to the telephone posts, and in underground lines in iron boxes put in pits in

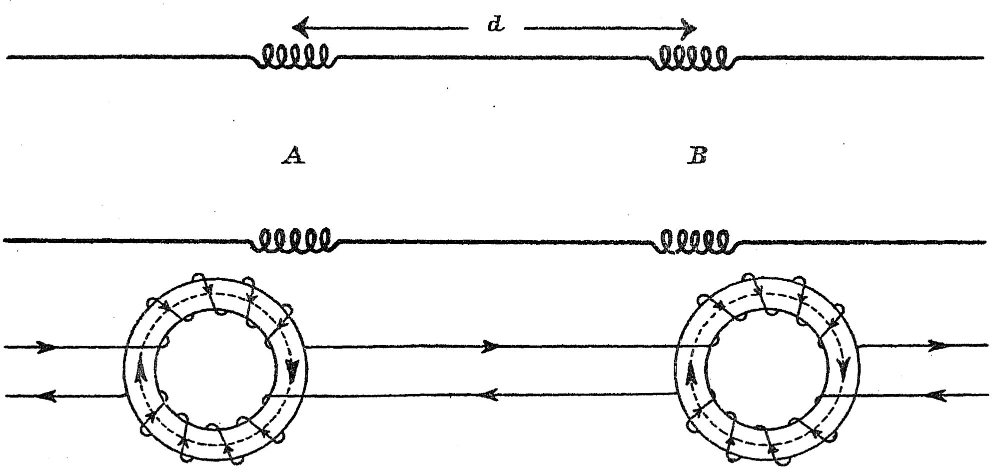


FIG. 38.—Mode of inserting Loading Coils at equal distances in a Telephone Cable.

the earth (see Plate 21). There was some difficulty in inserting them into submarine cables, but Messrs. Siemens devised a form of coil which only makes a slight protuberance on the cable (see Plate 22). This coil-loading was found to more than double the distance for good telephonic speech. It was very soon most extensively adopted in the United States and Germany, and introduced into Great Britain by the National Telephone Company, whose business was taken over in 1911 by the General Post Office.

The General Post Office have laid three loaded submarine cables, one to France, one to Belgium, across the English Channel, and one to

Ireland, across the Irish Channel. The French Government has laid a uniformly loaded cable from France to England. In addition to the coil-loaded English Channel submarine telephone (four-wire) cable manufactured by Messrs. Siemens Bros. and laid in 1910, and the uniformly loaded English Channel telephone cable made by the Telegraph Construction and Maintenance Company laid in 1912 for the French Government, there are three other unloaded Channel telephone cables, laid in 1891 and 1897, which provide telephonic communication with France and the Continent. In addition to the coil-loaded Anglo-French and Anglo-Belgian and Irish telephone cables, Messrs. Siemens Bros. have made and laid, in 1914, an Anglo-Dutch coil-loaded telephone cable and one for the Danish Government in 1915. Also one for the Swedish Government in 1920. Furthermore, during the war they laid, in all, about 236 nautical miles of similar cable for the British Government.

The General Post Office, since 1911, has been actively engaged in laying great lengths of underground coil-loaded telephone cables in Great Britain.

Enormous lengths of underground telephone cables have now been coil-loaded, both in Great Britain and the United States.

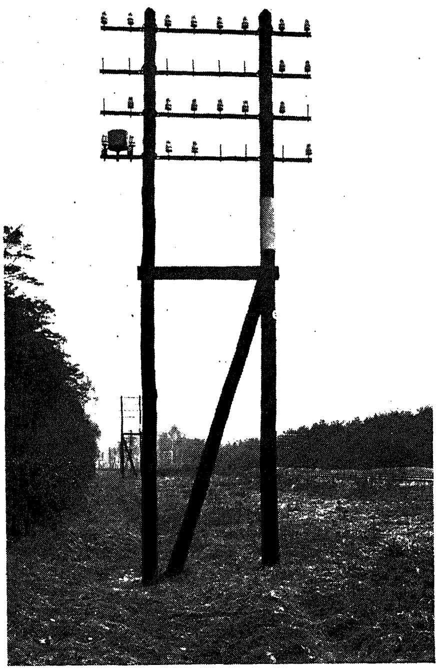
The longest coil-loaded aerial line in the world is the double telephone line, 3,400 miles long, from New York to San Francisco. Speech is not transmitted directly over this long distance, but there are at intervals devices called *thermionic repeaters*, which will be more particularly described in Chapter VII., which repeat the speech with renewed energy a dozen times on the way.

There is another long loaded aerial line from Berlin to Rome, but the longest in Great Britain are the London to Leeds trunk lines.

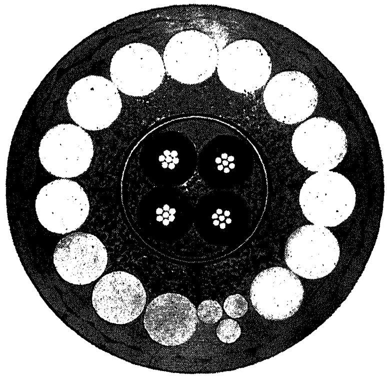
A very interesting and modern improvement is that of the *phantom circuit*, which enables us out of two independent telephone circuits to create a third circuit.

If there are two pairs of wires either in a cable (see Plate 21) or supported on telegraph posts, it is possible by twisting these pairs of wires round each other, or arranging them in a certain position, to prevent the speech currents in one pair of lines from creating interference with the

PLATE 21.

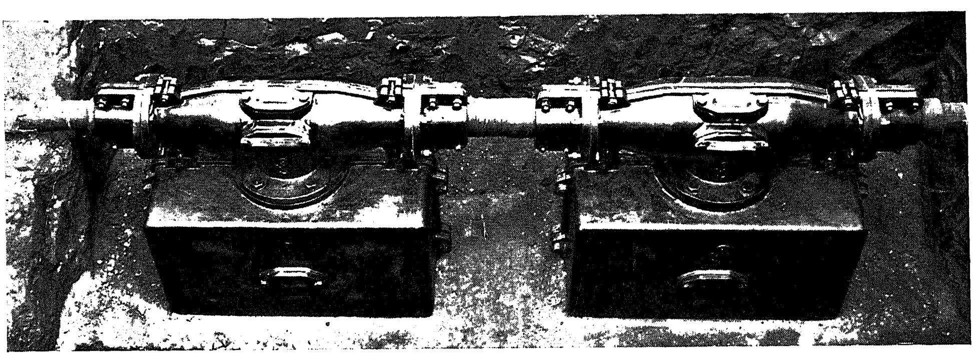


Loading Coil placed in an Iron Box and fixed to the cross-arm of a Telephone Post, as used in Overhead Telephone Lines.



[*By permission of Messrs. Siemens Bros.*

Section of the Anglo-French Coil-loaded (1910) Telephone Cable. It contains two pairs of telephone cables, the members of each pair being placed at the opposite corners of a square arrangement so as to provide two non-interfering telephone circuits.



Iron Boxes containing Loading Coils intended to be buried in the ground, as used in Underground Telephone Lines.

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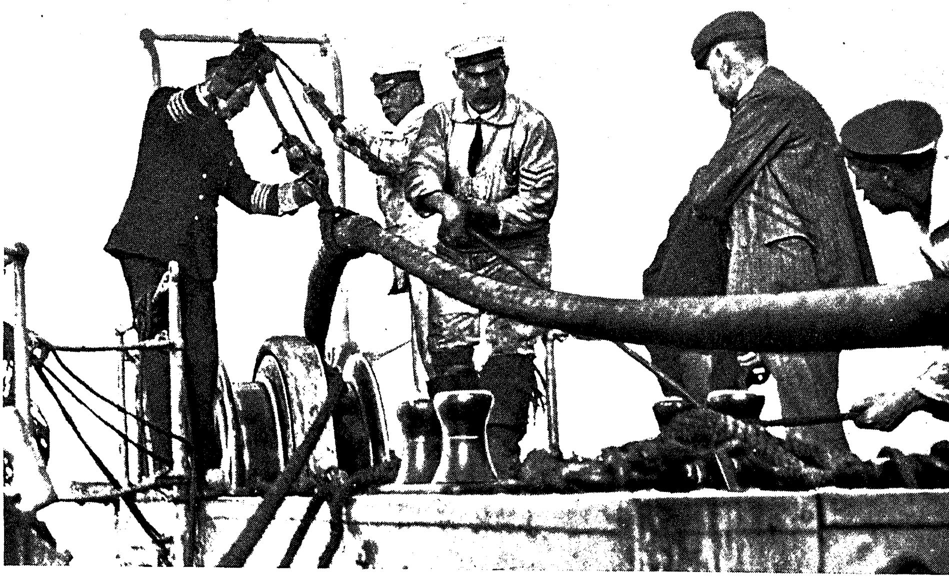
PLATE 22.



[*By permission of Lieut.-Colonel O'Meara, and of the Institution of Electrical Engineers.*

Laying the Anglo-French Coil-loaded (1910) Telephone Cable across the English Channel. The thick parts of the cable contain the loading coils, and are being carefully helped into the sea.

[*To face page* 107.

other pair by induction. When this is done each pair of wires becomes available for independent telephonic conversations. We can, however, use one pair of lines as a lead and the other pair of wires as a return for a third independent or *phantom* circuit (see Fig. 39).

In the case of the New York—San Francisco line this is done, and it therefore increases greatly the traffic carrying power of this long

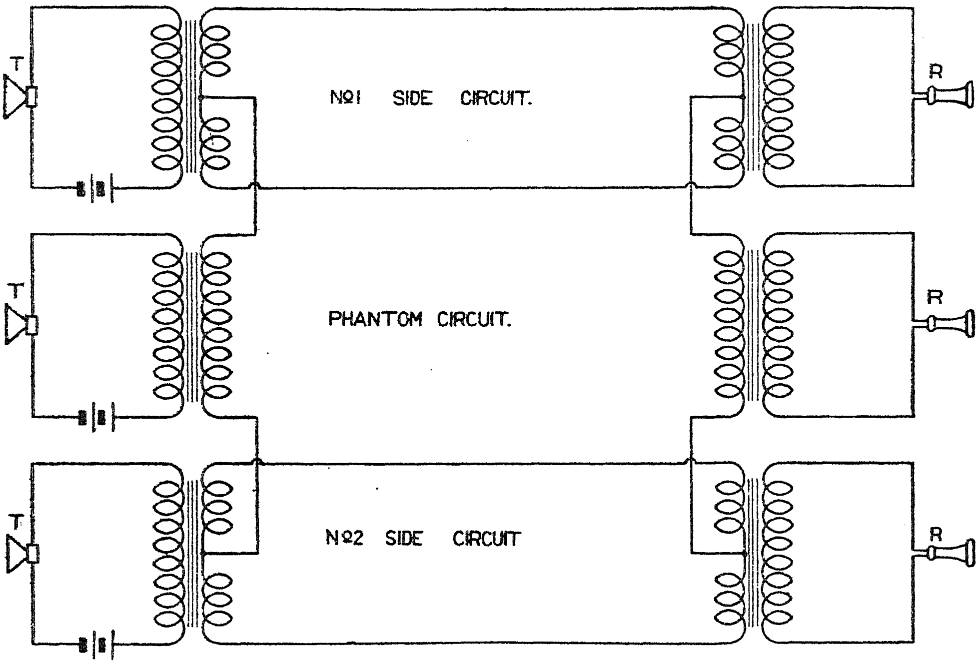


FIG. 39.—A Diagram showing the Arrangement of Telephone Lines known as the Phantom Circuit by which two pairs of Telephone Lines are made to do duty for three circuits, the extra circuit being called the Phantom Circuit. T is a microphone transmitter and R a magneto-receiving telephone.

and expensive line. Also, the line can be used at the same time for telegraphic purposes.

The use of loaded and phantom circuits is being largely extended at the present time in Great Britain by the General Post Office.

By the use of thermionic repeaters made as described in Chapter VII. of this book, greater economy in copper in long trunk lines may be possible.

Thus the London to Glasgow trunk telephone line is a double copper

wire circuit, each mile of which weighs 1,600 lbs., and hence the whole 400 miles required for its construction about 300 tons of copper wire. The cost of this was nearly £30,000 apart from the outlay for posts and insulators. The telephone line, when at all long, is by far the most costly item in the whole installation. Hence any invention which reduces the size of the wire or increases the traffic which can be got through it, or improves the speech quality, is of enormous importance.

Space does not permit us to describe the details of remarkable achievements due to inventions by A. Korn, of Munich, E. Belin, of Paris, and H. Petersen, of Denmark, by which copies of photographs and pictures can be transmitted by telegraph wire, reproducing a facsimile at a place hundreds of miles away.

In the eighty-three years which have elapsed since Cooke and Wheatstone put up their five-needle telegraph between Euston and Camden Town miracles of ingenuity have been performed in the conveyance of human intercourse through a copper wire stretched between two places, but this connecting wire is no longer necessary, and in our final chapter we shall describe the manner in which it has been found possible to dispense with it entirely and speak half round the world by waves produced in the æther of space.

CHAPTER II

DYNAMOS, ALTERNATORS, TRANSFORMERS AND MOTORS FROM 1870 TO 1920

A BRIEF reference has been made in the introductory chapter to the inventions which immediately grew out of Faraday's crowning discovery of the generation of an electric current in a copper wire by moving it across a strong magnetic field. The earliest magneto-electric machines based

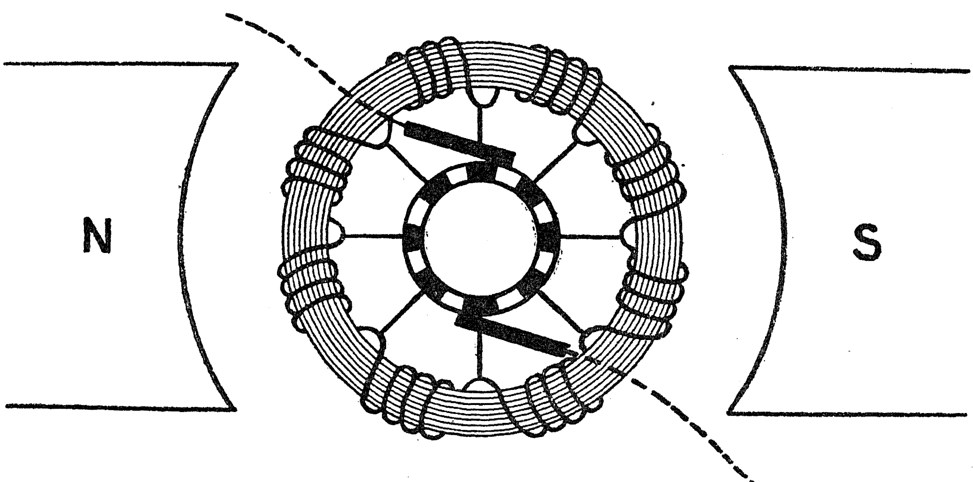


FIG. 1.—Diagram illustrating the Construction of a "Gramme Ring" Armature for a Dynamo Machine. The black and white sectors in the inner circle denote the end-on view of the commutator bars. The black spirals are the armature coils wound on a ring of iron wires or strips, and the black bars the "brushes." The parts marked N and S are the poles of the electromagnet which produces the magnetic field in which the ring rotates.

on this principle produced a current fluctuating in strength, and therefore unsuited for many purposes. In 1865 an Italian physicist, Pacinotti, devised a type of armature coil or bobbin of wire for generation of current by rotation between the poles of a magnet which was subsequently (in 1870) re-invented by Z. Gramme, a Belgian electrician, in improved form

and was the starting point for important advances. This armature or coil consists of a ring, formed by winding up iron wire, or tube formed of flat rings of thin sheet iron separated by paper or varnish (see Fig. 1). On this ring is wound an endless spiral of insulated copper wire divided into equal sections, and from the junctions between the sections wires are brought to a "commutator" which consists of a number of wedge-shaped copper bars arranged round an iron drum, the copper bars being insulated from each other and from the drum by mica. This drum is keyed on the shaft, to which the laminated iron ring or drum is also fixed, by radial bars. The armature revolves in a strong transverse magnetic field produced by an electromagnet (see Plate 1). Against the commutator two copper wire or gauze "brushes" press, these being on

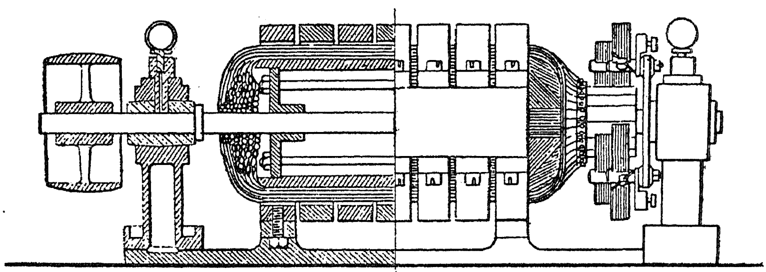


FIG. 2.—Section of a Siemens' Dynamo (type of 1873) showing the Drum-wound Armature and Bar Commutator.

opposite sides of the commutator, and from these brushes a steady electric current can be drawn off when the armature is revolved in the magnetic field. The current required to excite the electromagnets is drawn from the armature by connecting the ends of the magnetising field coils to the brushes. Such a self-exciting dynamo is called a shunt-wound machine. If a sufficient number of sections are provided in the armature winding, commonly called a "Gramme ring," each connected to a corresponding pair of bars on the commutator, the machine when driven at a steady speed will give a practically uniform direct electric current (see Plate 1).

In 1873 Von Hefner Alteneck modified the Siemens shuttle-shaped armature, already described in the Introduction, by winding over an iron drum, built up of thin iron disks superimposed with paper between them,

equispaced coils of wire in series with each other. He brought a connecting wire from the junction between each pair of coils to a copper bar on a commutator made as in Gramme's machine. He thus produced what was called the "drum winding" and this again formed the starting point for fresh developments (see Fig. 2 and Plate 2). Self-exciting dynamo machines having either Gramme ring or drum wound armatures of large size were before long constructed, and driven by steam power. The chief purpose for which these machines were then applicable was for electric arc lighting.

We shall discuss in Chapter III. the development of electric lighting, but, meanwhile, it may be said that in 1876 a Russian officer, Paul Jablochkov, invented his famous electric candle, consisting of two carbon rods placed side by side. An electric current springing between their tips created a brilliant electric arc. But this application necessitated the construction of dynamo machines giving an alternating electric current, or one flowing to and fro in the circuit, because with unidirectional currents one carbon consumes away faster than the other.

Special difficulties in connection with this form of electric lighting caused attention to be paid to the construction of direct-current dynamos giving a constant current always in the same direction, and of high electromotive force or pressure, and suitable, therefore, for working a series of electric arc lamps in which the carbons are placed in line with each other and the unequal wear of them does not matter.

In 1878 C. F. Brush, in the United States, invented a type of high pressure dynamo for electric arc lighting, and also a very practical form of self-regulating arc lamp intended to be worked thirty or fifty in series for street arc lighting, and much pioneer work of a useful character was carried out with it (see Plate 5, page 122).

In the following year, Mr. T. A. Edison and Sir Joseph Swan completed the invention of the carbon filament electric glow lamp as described in the next chapter, and this required for its operation dynamo machines giving electric current at perfectly constant pressure or potential.

About this date, therefore, dynamo machines were designed by numerous inventors for the production, (1) of variable electric currents at constant pressure for incandescent electric lighting; (2) for constant

or unvarying electric current but variable pressure for street arc lighting, by arcs in series.

The former were generally shunt-wound machines with Gramme or drum armatures, and the latter series wound machines with open coil armatures.

Soon after 1878 a fresh stimulus was applied to invention in connection with dynamo electric machinery. Mr. Edison had done much more than attack the problem of producing a small-unit incandescent electric lamp for domestic electric lighting. He saw that the possibilities of such lighting were essentially dependent upon the public supply of electric current from a generating station in the same manner that gas or water is supplied. Also that this supply must be a constant voltage or pressure and the energy metered to the consumer, and paid for by unit. He accordingly took large views and proceeded to think out all the details of such central station supply.

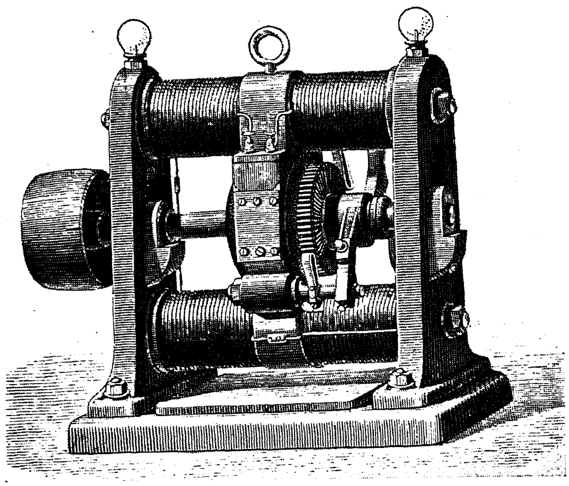
In 1879, after much preliminary work, Edison designed a form of dynamo, in which the field electromagnet consisted of two massive iron pole pieces with cylindrical interspace, these poles being the terminations of one or more pairs of long iron bars wound over with magnetising coils, and cross-connected at the top by an iron yoke. In the cylindrical polar gap he placed a drum-wound armature with laminated iron core, the shaft also carrying a Gramme commutator. These machines were designed to give electric current at a constant pressure of 110 volts or so (see Plate 1). In small machines the electromagnet consisted of one pair of legs, and in large machines of three or six pairs (see Plate 2).

The machines were designed to be driven either by a pulley and belt, by a steam engine, or else by coupling the armature shaft directly to the crank shaft of a steam engine.

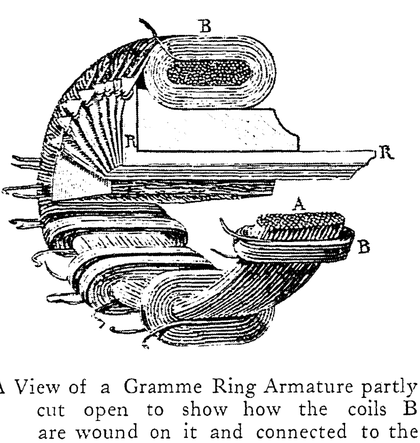
It was intended that several such machines should be worked "in parallel," that is, each independently driven, but sending their currents into a common pair of electric mains called "bus bars," so as to supply current as required at constant pressure for a variable number of incandescent lamps.

The evolution of electric supply stations will be considered in Chapter V. and we shall here merely discuss the improvements and

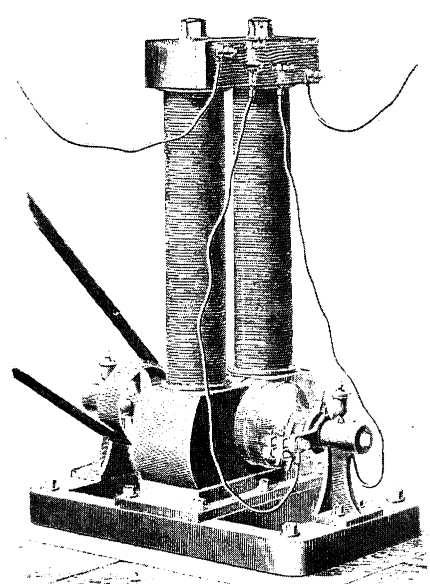
PLATE I.



A Gramme Dynamo (early type), showing the ring armature rotated in the field of a powerful electromagnet. (See page 110.)



A View of a Gramme Ring Armature partly cut open to show how the coils B are wound on it and connected to the commutator bars R.



Earliest Type of Edison Shunt-wound Dynamo with long thin electromagnet legs and drum wound armature, as built in 1882. (See page 112.)

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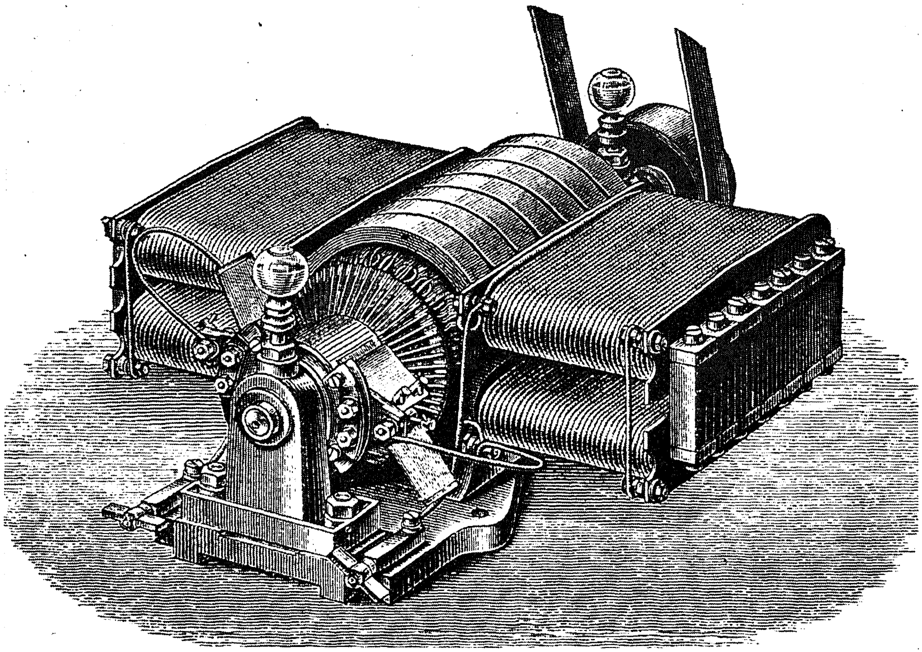
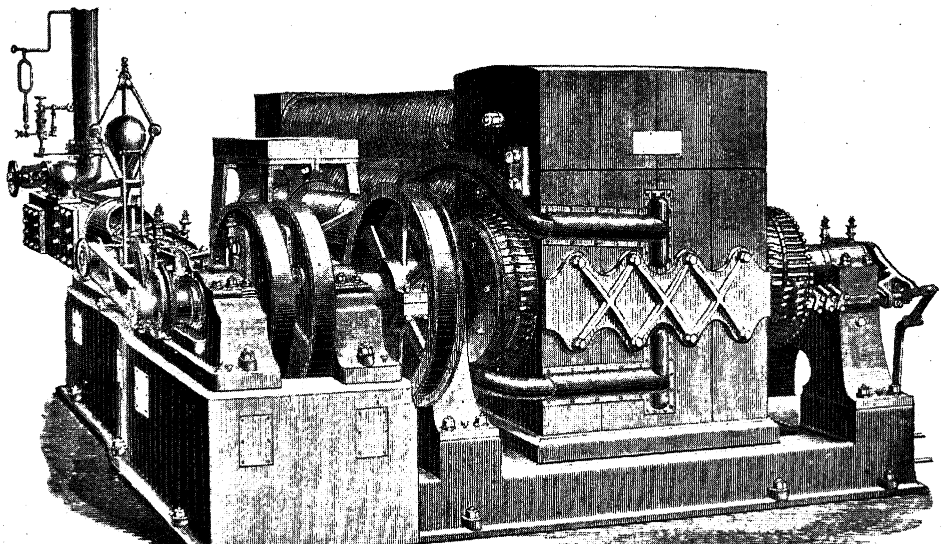
PLATE 2.



View of an Early Type (1873) of Siemens Self-exciting Dynamo with Drum-wound Armature and Bar Commutator.



Edison's Steam Dynamo (1882 type), having a drum-wound armature rotated by a direct-coupled steam engine. The armature gave a current up to 1,000 amperes at a pressure of 110 volts. The machine had a multiple-leg field magnet.

[*To face page* 113.

development of the dynamo itself. The principal problems which at once presented themselves were the "efficiency" of such machines and their design as regards required performance.

The dynamo in scientific language is an energy-transforming device. A certain amount of power is applied to the armature shaft to keep it in rotation, and the machine gives a certain electric current at a certain voltage at its brush terminals. This electric power output is reckoned in units called "kilowatts" (K.W.), or by the product of the constant electric pressure reckoned in volts, and the output in current in amperes, divided by 1,000. The prefix *kilo* means 1,000. Thus, a dynamo giving a current of 100 amperes at a pressure of 100 volts has an electric output of $100 \times 100 \div 1{,}000 = 10$ kilowatts.

Mechanical power is generally measured in "horse power" (h.p.), but this has nothing to do with a horse. A so-called horse power is merely a conventional unit of power or rate of doing work equal to that exerted when a weight of 1,000 lbs. is lifted 33 feet high against terrestrial gravity in one minute, or 55 lbs. lifted 10 feet high in one second. One horse power is equivalent to 0·746 of a kilowatt, or 1 kilowatt is nearly $1\frac{1}{3}$ h.p. If, then, we measure the power applied to rotate the armature and also the electrical output, both reckoned in kilowatts, the ratio of the latter to the former is called the *efficiency* of the dynamo. In the early machines this figure was rarely above 50 or 60 per cent., but in modern machines it reaches 90 or 95 per cent. The cause of the inefficiency of early machines was the internal energy losses due to bad design.

We have already seen in the introductory chapter that Faraday's cardinal discovery was that a bar or rod of metal when moved across lines of magnetic force has an electromotive force produced in it by this act of "cutting the lines." Between the poles of a magnet, lines of magnetic force stretch across from one pole to the other. If a drum having insulated copper wires parallel to its axis is rotated in this magnetic field with its axis perpendicular to their direction, it is clear that at each complete revolution each wire will cut across the magnetic lines just as a knife could be moved through a thin jet of water or other fluid. Not only is a current of electricity, therefore, induced in the insulated copper

wires, but electric currents, called "eddy currents," will be created in the iron drum itself or in any rods or bolts passing through it. These eddy currents dissipate energy uselessly and, in addition, there is an energy loss due to the repeated reversal of direction of the magnetisation of the revolving iron core forming the drum.

Then again there is an expenditure of energy in the current required to maintain the magnetic field, viz., in the windings of wire on the magnet legs. Also some loss in friction of bearings of the armature shaft and in other ways. The electromotive force produced in each wire of the armature drum is proportional to its length, to its velocity across the field and to the strength of the magnetic interpolar field. Hence, for a given armature required to produce a given voltage the necessary speed of revolution will be greater the less the magnetic field. Accordingly a strong magnetic field is desirable, and for this purpose a correct proportioning of parts is essential. Before 1880 or 1882 dynamo construction could hardly be said to have been a scientific art. It was mostly an affair of clever guessing in the light of past failures.

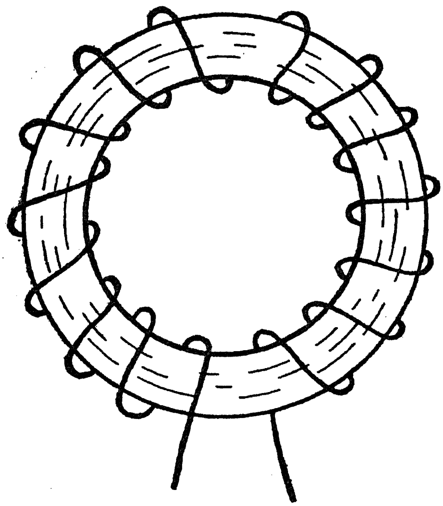


Fig. 3.—An Iron Ring wound over with a spiral of silk-covered Wire, which, when traversed by an Electric Current, magnetises the Iron in the direction of the broken lines. It thus forms a "poleless" electromagnet. The iron is then said to be traversed by magnetic flux.

The first step towards a better practice was a study of the laws of the magnetic circuit. If we wind on an iron ring a spiral of insulated or cotton-covered wire, in which the beginning and end of the spiral are close together, we have a typical, simple magnetic circuit (see Fig. 3). If we send an electric current through the wire the iron is magnetised along the direction of the ring perimeter, but since the ring is self-closed, there are no free magnetic poles. Nevertheless, there is a magnetic state in the iron called *magnetic flux*, and this is regarded as an effect produced by the

magnetic force, which is proportional to the product of the number of turns of wire on the ring and to the current, reckoned in units called an *ampere*, flowing through it, otherwise called the *ampere-turns* on the ring. If we measure the mean length of the ring circumference and calculate the ampere-turns per unit of this length, this product when multiplied by a certain constant which is nearly equal to $1\frac{1}{4}$ (more exactly $4\pi/10 = 44/35$), gives us an exact measure of this magnetising force. If we reckon the magnetic flux per unit of area of cross section of the ring we have the so-called *flux density* in the iron. This is stated in terms of units called lines of magnetic flux per square centimetre. If we increase the magnetising force the flux density increases, but not indefinitely. The relation of the two quantities can only be expressed by drawing a curve called a *magnetisation curve* (see Fig. 4). The ratio of magnetic flux density to magnetising force is a measure of the so-called *permeability* of the material for that flux density. It is not a constant quantity, but increases up to a maximum at a flux density of about 5,000 lines of flux per square centimetre.

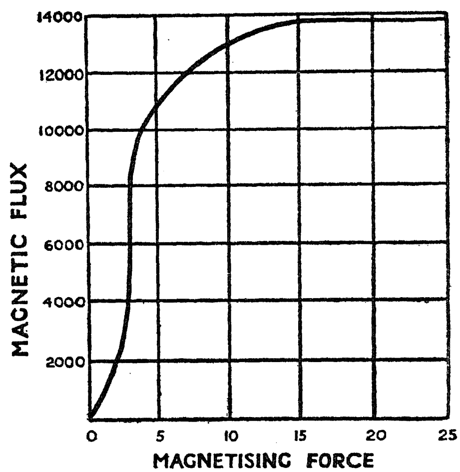


FIG. 4.—A Magnetisation Curve for an Iron Ring. If we wind an iron ring (as in Fig. 3) with a spiral of insulated wire and send an electric current through the wire, the magnetising force is proportional to the product of the number of turns of wire and to the strength of the current. If we increase the current, the magnetic flux in the iron increases very rapidly up to a maximum value. A curve delineating the way in which the flux increases with the force is called a magnetisation curve.

In the above case the magnetic circuit or path of the lines of flux is homogeneous, the material all being iron. Suppose, however, that the ring has a couple of transverse cuts made across it, the magnetic circuit then consists of four parts; two of these are the portions, large and small, of the iron circuit, and two are the air gaps due to the cuts (see Fig. 5). The magnetic circuit is then non-uniform.

In the dynamo the circuit is even more complex. The iron part con-

sists of the yoke, legs and pole pieces, and also of the armature core. The air part is the two gaps between the armature core and the pole pieces. If we have for each of these the dimensions and a magnetisation curve for each material we can pre-determine the ampere-turns or total magneto motive force to be put upon the magnet legs to produce the required flux in the air gaps and, hence, the required electromotive force of the completed dynamo. The electric current flowing in the wire wound on the legs of the electromagnet which forms the so-called field magnet of the dynamo may be regarded as creating in the magnetic circuit a state called magnetic flux, existing along lines which are endless lines and complete their circuit by passing partly through the iron, partly through air in the gaps, and partly in the iron armature core. The currents generated in the armature coils by their motion through the magnetic field also create magnetic flux in the circuit, and as a broad general rule the armature currents oppose in magnetising action the field magnet currents. The result is to produce a distortion of the interpolar magnetic field as in Fig. 6, which is called armature reaction and requires to be pre-determined in making a design for a dynamo.

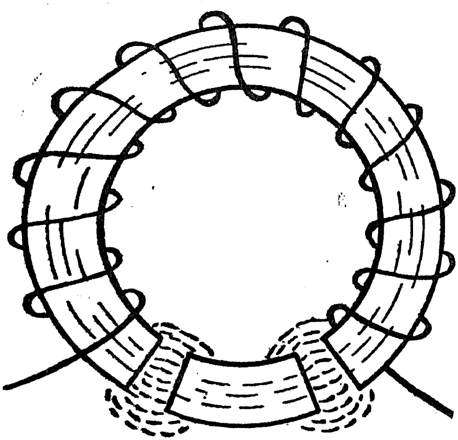


FIG. 5.—A Complex Magnetic Circuit, consisting of an Iron Ring having two Gaps or Cuts in it. A magnetising spiral is wound on the ring and produces in the circuit magnetic flux, the lines of which are indicated by the dotted lines. The path in which the flux travels is partly iron and partly air. The flux lines spread out in crossing the air gaps.

These principles and methods of design were gradually evolved in England and in the United States by the study given to the magnetic circuit. An important paper was read to the Royal Society of London in 1886 by Drs. J. and E. Hopkinson, in which these methods were applied to dynamo design, but much valuable work was also done by Professor G. Forbes, Colonel R. E. B. Crompton, Dr. S. P. Thompson, Dr Gisbert Kapp, Mr. James Swinburne, Messrs. Ravenshaw and Hawkins in England and Messrs. Parshall and Hobart in the United States in bringing dynamo

design from an empirical to a scientific process. Mechanical and general structural improvements were also made.

The demands of dynamo builders led to the production of improved

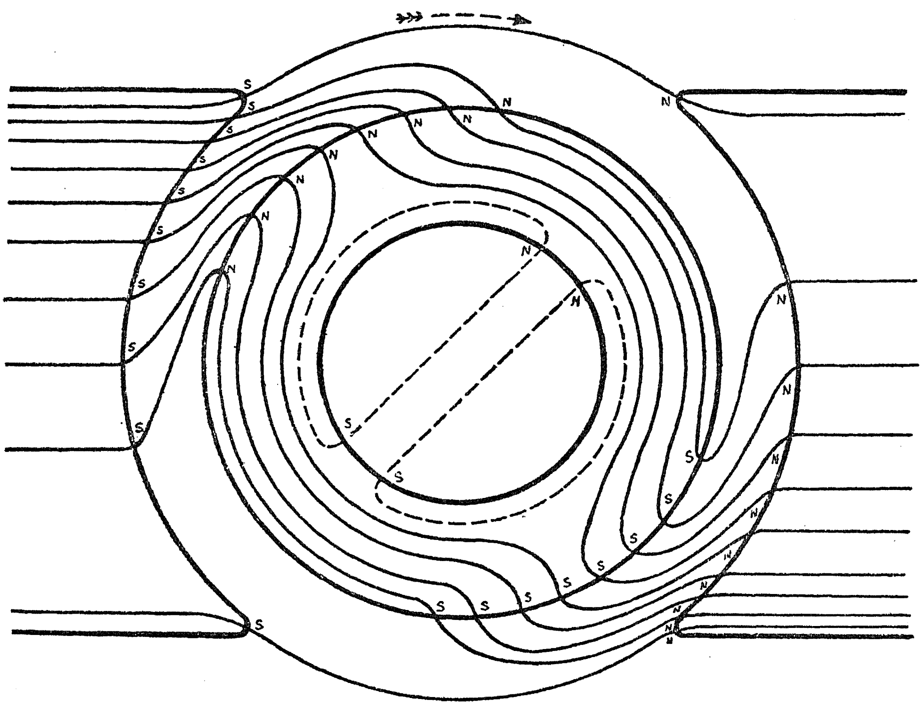


FIG. 6.—Diagram showing the Distortion of the Lines of the Interpolar Magnetic Field of a Dynamo, having a ring type of armature core, by the currents induced in the armature windings by their rotation in the magnetic field. The curved black lines represent the lines of magnetic flux and the circles the outline of the ring core and field poles.

qualities of iron and steel both in the form of castings and thin sheets, in which high magnetic permeability was the chief feature.

As the result of his researches Dr. Hopkinson improved the Edison dynamo by abolishing the multiple iron legs of the magnets and forming the iron cores of the field magnets of a pair of single thick, and much shorter cylinders of high permeability iron. This, with other improvements in detail, gave us the Edison-Hopkinson dynamo for incandescent electric lighting (see Plate 3). By strengthening considerably the magnetic

field the speed of the machine was reduced and it became possible to couple the armature directly to a high-speed steam engine and get rid of belt driving. Colonel R. E. B. Crompton made similar improvements in the Gramme dynamo.

The Edison Electric Light Company, of London, was formed in 1881 to carry out Edison's system of incandescent lighting. One field of operation which presented itself was in ship lighting. Before long an invitation was received from the Admiralty to tender for the electric lighting of some Indian troopships. The Admiralty, however, could not afford space on board ship for belt-driven dynamos, and the question of reducing speed and driving by direct coupling to a Brotherhood three-cylinder high-speed steam engine was therefore considered. The author and Dr. J. Hopkinson were at that time scientific advisers of the Edison Electric Light Company, and the matter was carefully discussed, with the result that by re-designing the field magnets Dr. Hopkinson was able to reduce the armature speed so as to permit of direct driving and yet maintain the required electromotive force at the dynamo terminals.

Soon after that date the Willans high-speed steam engine began to be employed for the same purpose, and other engine builders provided suitable high-speed engines for direct coupling to dynamos.

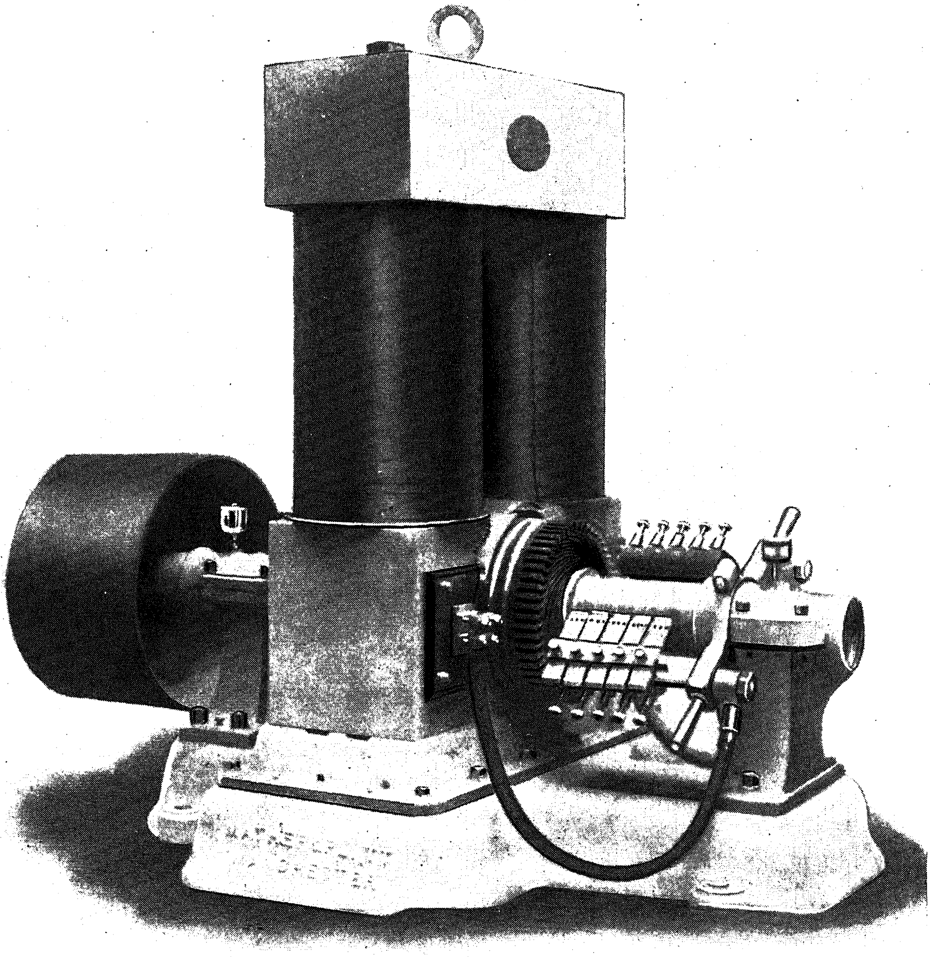
The public demand for arc lighting and the necessity of working a large number of such arcs in series led to the invention of several forms of direct-current dynamo giving a constant current but a variable electromotive force.

Of these, the most remarkable were the arc lighting dynamos of C. F. Brush, already mentioned, and that of Elihu Thomson and Edwin J. Houston (see Plates 4 and 5, pages 119 and 122).

The first of these machines is technically termed an open-coil dynamo because the whole of the coils on the armature are not in series or use at once.

In the Brush dynamo there are a number of coils (say eight) wound upon a laminated iron ring in the Gramme manner. Pairs of coils at opposite ends of a diameter of the ring are connected in series and the terminals brought to a pair of insulated curved metal plates called a commutator, against which collecting brushes press. The commutator

PLATE 3.



dison-Hopkinson Dynamo with Drum Armature, Bar Commutator and Shunt-wound Field Magnets.
(See page 117.)

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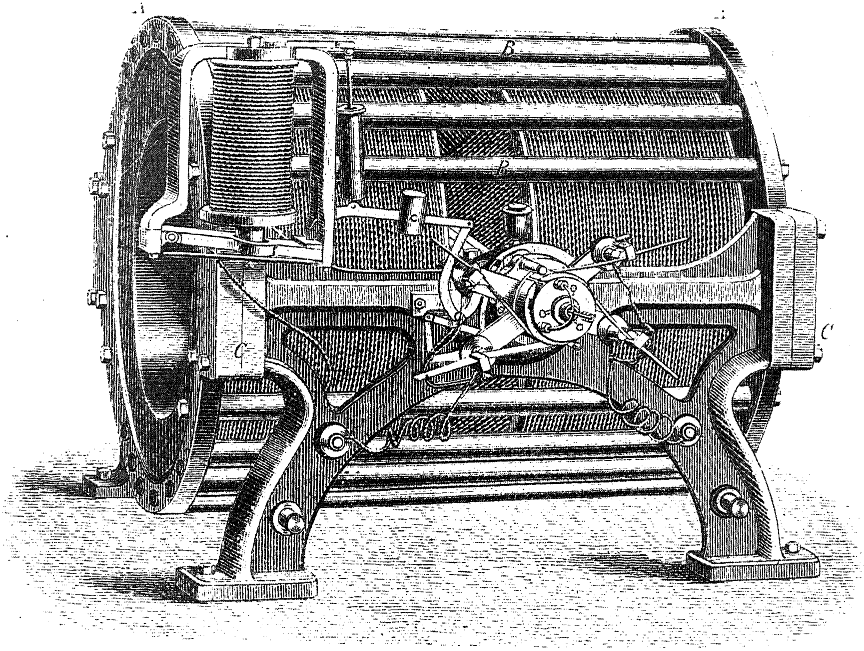
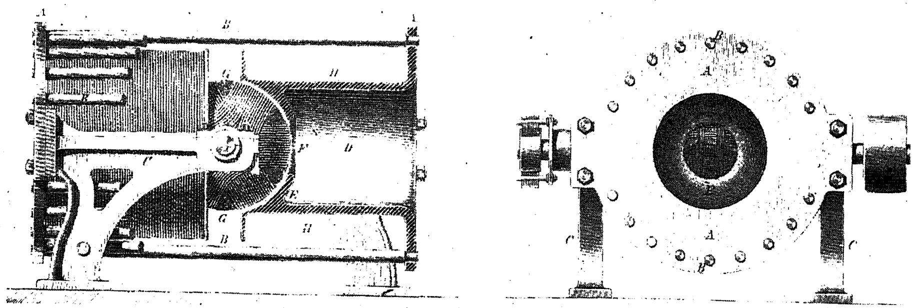


Thomson-Houston Arc Lamp Dynamo giving a constant current for arc lamp lighting. The dynamo self-adjusts its voltage to suit the number of arc lamps which may be put in series. (See page 119.)



Half-section and End-on View of a Thomson-Houston Arc Lighting Dynamo giving a constant current at a high voltage for working street arc lamps in series.

[*To face page* 119.

plates are so fixed that current is collected from the coils only when the E.M.F. in them is near a maximum value in one direction. Each pair of coils is in this manner connected to a pair of commutator plates. A coil in which no electromotive force is being generated at that moment, because of its position in the magnetic field, is excluded or cut out from the circuit which includes the active or useful coils.

Two pairs of brushes are employed, which are so set that they connect one pair of coils in series with two other pairs connected in parallel, whilst one pair of coils is cut out or not used. During each revolution the changes of connection so occur that the coils cut out are those in which there is at that moment no E.M.F. The machine really consists of four separate dynamos, which are connected in parallel and series as required.

The machines give a practically uniform current, say of 10 amperes at 2,000 volts or 2,500 volts, which is sufficient for working forty or fifty arc lamps in series. There are special arrangements for reducing this voltage if lamps are extinguished in the series.

Another remarkably interesting arc lamp dynamo is the Thomson-Houston machine. It has a curious ball-shaped armature on which are wound six coils arranged in three pairs. One set of ends of these coils are connected together and the other three respectively to the curved plates of a three-part commutator (see Plate 4). This ball armature revolves in a magnetic field produced by an electromagnet with cup-shaped pole pieces.

Against the commutator two pairs of brushes press which connect the three coils so that two are in parallel and in series with the third coil. The electromotive force of the machine is regulated by shifting the position of the brushes by means of an electromagnet, which is automatically operated so that the current is always kept constant at the right strength, say 10 amperes, for working the arc lamp in series, and the voltage is varied in accordance with the number of lamps placed in series. This system of self-regulation is very ingenious, and in addition there is an effective form of air blast which continually blows out the spark at the brush contacts as the brushes pass from one sector to the next.

At one time a considerable amount of all the arc lighting of the world was conducted either by Brush or Thomson-Houston open-coil dynamos,

which it may be noted had their field magnets excited by coils in series with the external circuit.

In the ten years between 1880 and 1890 the dynamo was thus perfected so that from being a machine very liable to breakdown and failure, especially in electrical insulation, and of low efficiency, perhaps not more than 60 per cent., it was raised to the condition of being a highly efficient energy-transformer of 90 to 95 per cent. efficiency, capable of sustaining long non-stop runs without overheating or failures mechanical and electrical.

The development of public electric generating stations made demands for strict attention to specified performance, and dynamo design soon became a specialised study.

The modern typical form of direct-current constant voltage dynamo of large output for public electric supply is the multipolar type direct-coupled to a high-speed steam engine, either reciprocating or turbine (see Plate 5).

In the multipolar dynamo the field magnet consists of a massive ring of high permeability steel from the inner perimeter of which project four, six, eight or more iron pole pieces which are each surrounded by a magnetising coil of insulated wire. An electric current is sent through these coils so that the inward projecting magnetic poles are alternately north and south round the ring. In the central space a drum armature revolves, consisting of a massive core of circular sheets of thin iron or steel insulated from each other and having longitudinal grooves along the cylindrical exterior, in which insulated bars or wires of copper are placed in which electric currents are induced by the rotation in the magnetic field. A multiple-bar commutator of large diameter serves to rectify the currents. Such a multipolar dynamo is equivalent to a number of bipole dynamos joined in parallel. A machine of this kind is generally driven by direct coupling to the shaft of a steam engine.

The voltage or electric pressure for which direct-current dynamos are designed depends upon the nature of their service. For incandescent electric lighting on the three-wire system, as described in Chapter V., it is generally 440—500 volts. For electric traction from 500 to 1,500 volts, and for arc lighting and other purposes still higher voltages are required.

We must then consider in the next place the types of dynamo which give an alternating current, viz., one which reverses the direction of the current at frequent intervals, it may be fifty times a second, or for certain purposes it may be 1,000 or 20,000 times a second. These machines are called *alternators*. Some of the earliest machines for the production of electric currents by mechanical power due to the rotation of coils of wire between or in front of the poles of permanent steel magnets, were, as we have seen in the introductory chapter, alternating current machines. The use of permanent steel field magnets is now almost restricted to magneto ignition machines used in motor vehicles, otherwise every alternator requires the addition of a direct-current dynamo, called an exciter, to provide the direct current for energising the electromagnets which provide the permanent magnetic field.

This exciter is most usually fixed to the same shaft as the alternator rotating part and driven with it (see Plates 6 and 12, pages 123 and 137).

A modern form of alternator consists of a star-shaped electromagnet, viz., one constructed like a wheel without a rim, of massive high permeability steel. The spokes of this wheel are surrounded by coils of insulated wire and so arranged that when a direct current of electricity flows through the coils the spokes are magnetised, with outer ends, alternately North and South. This wheel forms the flywheel of a steam engine or other motor. The ends of the magnetising circuit are brought down to two insulated brass rings fixed on the shaft. Against these press two brass-wire brushes by means of which the magnetising current provided by a direct-current dynamo fixed on the same shaft is sent into the coils when the star-shaped magnet is revolving. This multiple pole electromagnet revolves within an iron ring to the inner side of which are fixed inwardly projecting lugs built up of thin sheet iron. These lugs are surrounded by coils of insulated wire, which are called the armature coils, and the winding on these coils is alternately in one direction or the opposite. Corresponding to each magnetic pole on the field magnet there is an armature coil, so that if there are twenty magnetic poles there are twenty armature coils.

When the magnet is excited by the direct current from the exciter dynamo a magnetic flux streams out from each North pole, passes through

a corresponding armature coil and through the iron ring frame and then back through the next armature coil into the adjacent South pole of the magnet, and so completes its circuit.

The reader should bear in mind that a line of magnetic flux is always an endless line, and must complete itself into a closed loop in the magnetic circuit. It will easily be seen that when the star-shaped magnet revolves, the lines of magnetic flux, which are emitted by each North pole, like

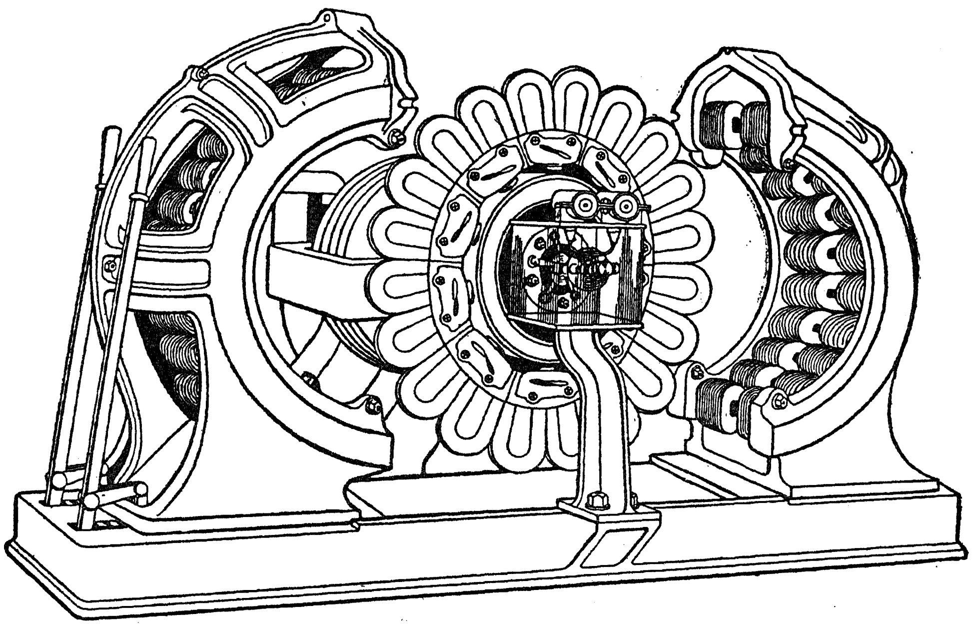
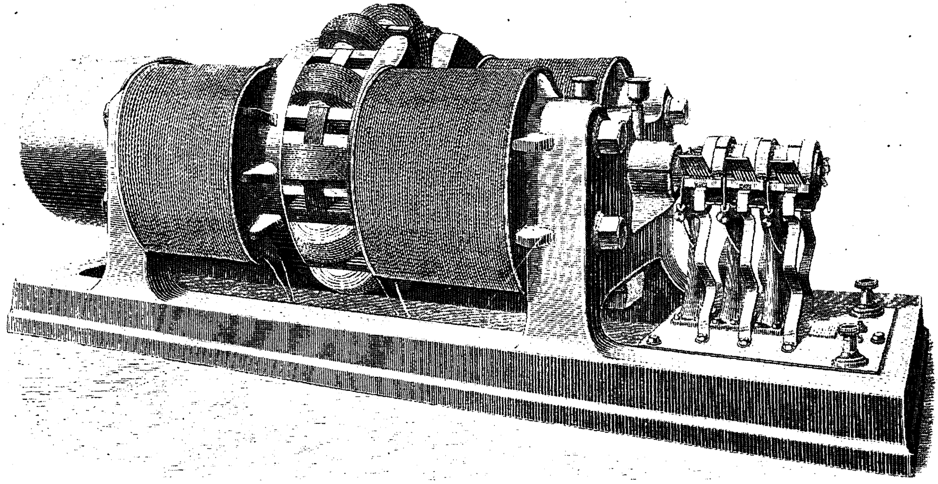


Fig. 7.—A View of a Ferranti Alternator with the Field Magnet Frame withdrawn in two parts so as to show the Armature which revolves between their poles when they are brought together.

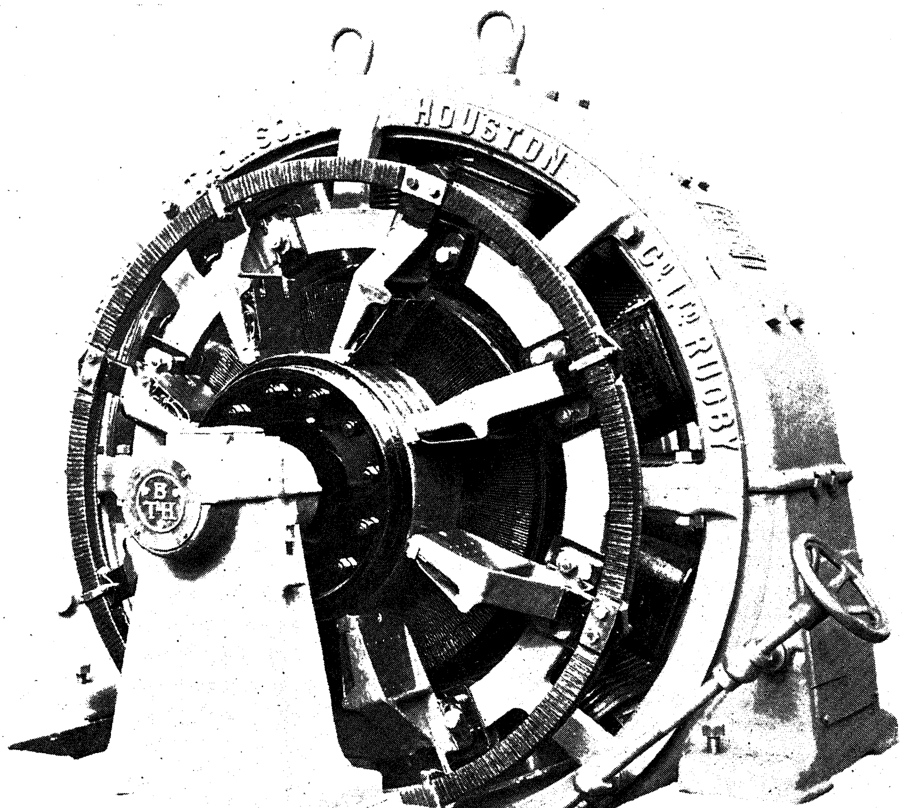
smoke from a chimney, and sucked back into each South pole, are reversed in direction through the armature coils. Faraday showed that when lines of magnetic flux are either inserted into or withdrawn from a closed copper wire loop or coil the result is to create in the coil an electromotive force proportional to the *rate* at which the number of lines of flux is being changed at that instant.

Hence, if lines of magnetic flux are alternately inserted, first in one direction and then in the opposite, into a coil of wire, the effect is to create in that coil an alternating or to and fro movement of electricity.

PLATE 5.



Arc Light Dynamo of C. F. Brush (1878 type) giving a direct current of 10 amperes and high voltage for working electric arc street lamps in series. (See page 118.)



[*By permission of the British Thomson-Houston Co., Ltd.*

A Modern Type of Direct-current Multipolar Dynamo as used for the production of electric currents for public electric lighting by incandescent lamps or other public supply of current (1921). Such a machine consists, in fact, of a number of bipole machines coupled in parallel or series. It has a large cylindrical multiple-bar commutator with many sets of brushes making contact on it. (See page 120.)

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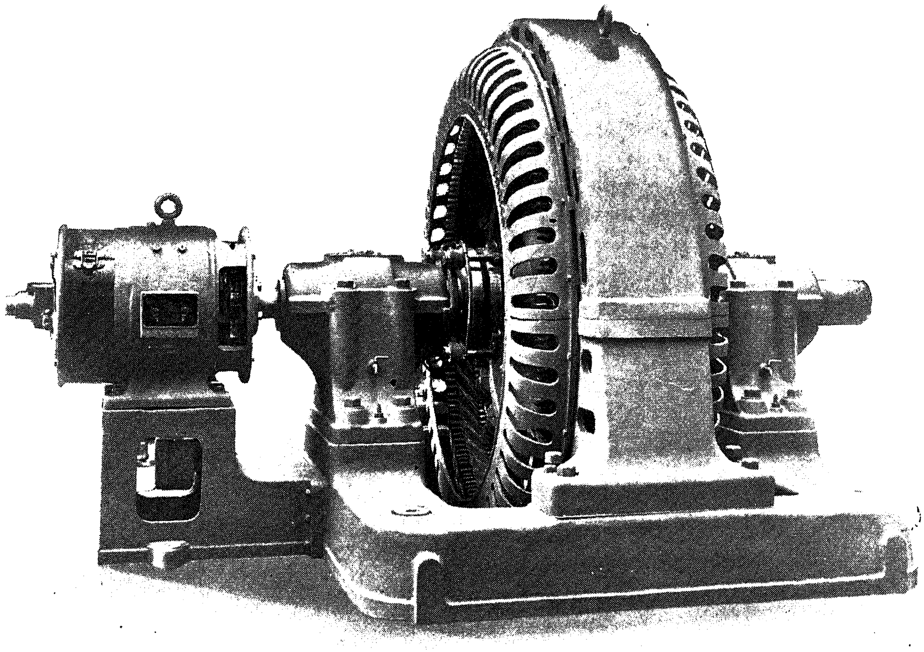
PLATE 6.



[*By permission of Messrs. the G. E. Co., Ltd.*

A Modern Type of Alternator, having the exciter or direct-current dynamo for providing the exciting current for the field magnets of the alternator fixed to the same shaft. (See also Plate 12, page 147.)

[*To face page* 123.

Based on this principle many different types of alternator were designed between 1878 and 1890 by Gramme, Westinghouse, Ferranti, Kapp, Parker, Mordey, and Messrs. Ganz, of Budapest. Mr. Ferranti especially devoted his attention to the design and construction of large alternators for public electric supply, and the introduction of this system of supply gave rise to much controversy as to the relative merits of direct or alternating currents for this purpose, to which further allusion is made in Chapter V.

In the Ferranti alternator the field magnets are fixed and the armature coils revolve. The machine consists of an iron carcase, formed of two massive rings of iron, placed with planes parallel to each other (see Fig. 7). From the inner opposed faces project pole pieces of iron, which are surrounded by magnetising coils, connected in such manner that when an exciting direct current is sent through them, lines of magnetic flux spring across from the poles of one ring to those of the opposite ring. These groups of lines of flux are alternately directed one way and the other. The revolving shaft of the machine is placed perpendicularly to the plane of the ring frame and carries a hub, to which a number of flat armature coils are fixed (see Plate 7, page 128). These consist of copper tape, about an inch in width, wound up on a core, with insulating tape between each turn, into a form of oval coil. A number of these coils, equal in number to the field magnet poles on each ring of the carcase, are fixed to the hub, and so arranged that, looked at from one side, the windings of the successive coils are alternately right and left handed. The coils are joined in series and the extreme ends brought down to two insulated copper rings on the shaft, against which two metal brushes press, to draw off the alternating current. The coils are fixed with their planes perpendicularly to the shaft, so that as the latter revolves these coils are forced to move edgeways through magnetic fields having lines of flux in bunches, directed alternately in one direction or the opposite. The result is to generate in the rotating armature an alternating current of electricity. Some of Mr. Ferranti's alternators were designed, as mentioned in Chapter V., for very high pressures, viz., 10,000 volts or more, for public electric supply.

The types of alternator above described are called single-phase machines because they give a single alternating current.

There are other types called two- and three-phase alternators, made as follows :—

Referring to the type of alternator above described, in which the armature consists of a number of flat coils placed on the inner surface of a fixed ring frame, suppose that there are two sets of such coils with the individual coils sandwiched in alternately between one another, each series of coils forms a separate and independent armature. Let the star-shaped field magnet have a number of poles NS equal to the number

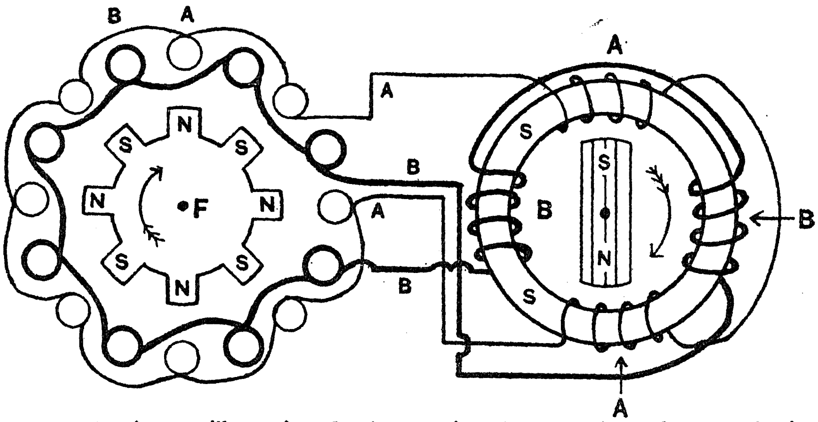


Fig. 8.—A Diagram illustrating the Construction of a Two-phase Alternator having two armature circuits AA and BB intertwined so that two alternating currents are generated which differ in phase by 90 degrees or are one-quarter of a complete period out of step with each other. The star-shaped field magnet F is shown in the centre. These two-phase currents can be used to create a revolving magnetic field by means of two windings of wire placed on an iron ring, as shown in the right-hand side of the diagram.

of coils in either circuit. For the sake of distinction we may call these two armature circuits AA and BB (see Fig. 8). The electromotive force generated in each coil at any instant, in virtue of Faraday's law of magneto-electric induction, depends upon the *rate* at which the magnetic flux perforating through the coil at any instant is changing. It is easy to see that when a field magnet pole is just opposite an armature coil this rate will be zero, but when the armature coil is half way between a north and south field pole, that rate will be a maximum. Hence, if we stagger or alternate two sets of coils in two independent armature circuits the electromotive force in one circuit will be a maximum at the

instant when that in the other is zero. This electromotive force does not spring into existence or vanish suddenly, but grows up and dies away gradually in each coil. Hence, in each circuit there is an alternating current, but these currents are said to *differ in phase* by 90°. A machine so constructed is called a two-phase alternator. Similarly, by employing three sets of armature coils sandwiched in between each other and forming three complete independent armature circuits, and using a field magnet with a number of radial poles equal to the number of armature coils in either circuit, we can make a three-phase alternator which yields

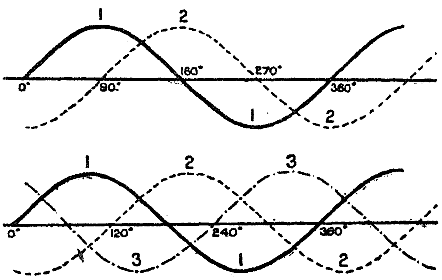


FIG. 9.—The Wave Lines, firm (1) and dotted (2), represent Alternating Currents of Electricity. The upper diagram denotes two alternating currents differing in phase by 90 degrees, and the lower diagram three alternating currents differing in phase by 120 degrees.

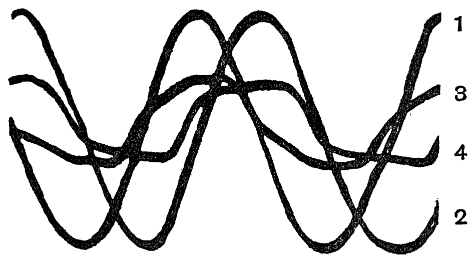


FIG. 10.—Curves 1 and 2 denote two Alternating Electromotive Forces or Voltages differing in phase by 90 degrees, and curves 3 and 4 two corresponding Alternating Currents lagging in phase behind their voltages 1 and 2. These curves represent two-phase voltages and currents.

three independent alternating currents, differing in phase by 120°. The special uses of such alternators will be considered later on.

Since an alternating current is one which periodically changes its direction of flow in a circuit, its progress in time can best be represented by a wave line, the height or ordinate at any point representing to some scale, the strength of the current at the time represented by the horizontal distance from some datum point (see Fig. 9). We may draw on the same diagram two such lines not in step with each other and, therefore, representing two alternating currents not in phase with each other, that is, not having their zero or maximum values at the same instant.

We can also represent on the same diagram an alternating current and an alternating electromotive force, and these will not be in phase

with each other if the circuit has electric inertia or inductance (see Fig. 10). In this latter case the current will lag behind the E.M.F. in phase.

There is another type of alternator, called an inductor alternator, to which reference must be made on account of its importance in connection with wireless telegraphy.

In an alternator intended to give a current of high frequency, that is one reversing in direction many hundreds of times per second, this frequency can only be obtained either by increasing the number of armature

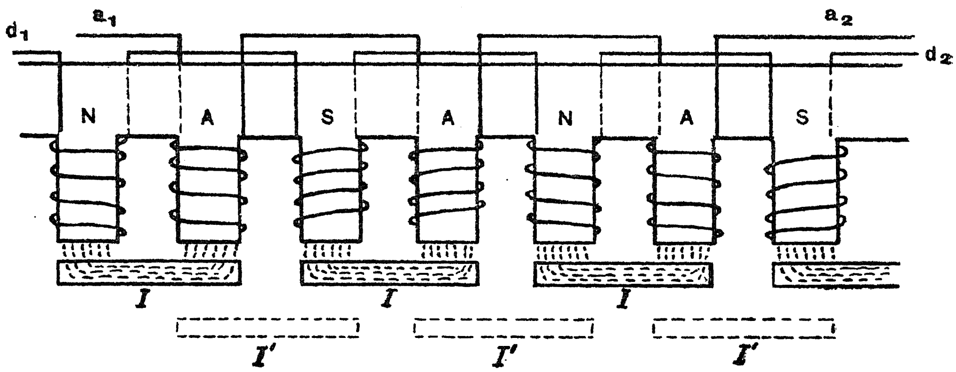


FIG. 11.—A Diagram illustrating the Structure of an *Inductor Alternator*. The teeth N A S are formed of bundles of sheet iron projecting inwards from an iron ring, of which a portion is shown for simplicity straightened out. These teeth are wound over with insulated wire, and the coils on alternate teeth are in series, forming an armature circuit a_1 a_2, and a magnetising or field circuit d_1 d_2. Through the latter a direct current is sent, magnetising the alternate teeth—North poles N and South poles S. I I are the iron teeth of the inductor disk. When these teeth are in positions I I they facilitate the flow of magnetic flux down the poles N and up the armature poles A. When the teeth move forward so as to come over the dotted positions I′ I′ they cause the flux to reverse its direction and flow down the poles A and up the poles S, thus causing an alternating current in the armature circuit a_1 a_2.

coils or else the speed of the rotating portion. There is a well-marked limit to the safe speed at which either the field magnet or the armature of an alternator can be rotated. Hence a type of alternator has been evolved in which both the field magnet coils and the armature coils are fixed, and the only rotating part is a well-balanced disk of steel with teeth or grooves in its edge.

Imagine a ring of iron with inwardly projecting teeth, and let magnetising coils traversed by a direct current be wound on every alternate tooth, so as to make these field poles north and south poles alternately

as we go round the ring. On the intermediate teeth let other armature coils be wound which are joined in series (see Fig. 11).

In the interior space let an iron disk having projecting teeth revolve, and let each tooth be sufficiently wide to cover the space including one projecting field pole and one armature pole, as in Fig. 11.

Then, if the clearance between the outer surface of these wheel teeth and of the inwardly projecting poles is very small, these iron teeth will afford a path of high permeability for the lines of magnetic flux generated by each field pole to return one way or the other through an adjacent armature coil. By properly joining up these armature coils it is possible to cause the revolution of the toothed iron wheel to continually reverse the direction of the magnetic flux through the armature coils as it revolves, and thus create an alternating current in the armature circuit merely by the revolution of the toothed iron wheel. Such a machine is called an *inductor alternator.* These inductor alternators can be made to give very high frequency alternating currents for use in wireless telegraphy.

The development of the alternator was accompanied by the development and improvement of the alternating current transformer to which we must next refer.

One of Faraday's great discoveries was that of the induction of electric currents. He wound upon an iron ring two insulated wires. Through one of these he passed a direct or unidirectional electric current from a battery, and he found that, whenever this primary current was started or stopped or changed in strength, a transitory current made its appearance in the other or secondary circuit * (see Plate 8, page 129).

This fundamental instrument was soon developed into the induction coil by the researches of Callan, Sturgeon, Page, Henley and others. Later on Ruhmkorff and Apps made very important advances in making high tension induction coils.

It was soon found that, if a bundle of fine iron wires was wound over with a primary coil of cotton-covered copper wire in two or three layers through which a current from a battery could be allowed to flow, and

* The original apparatus made by Faraday himself is still carefully preserved in the museum of the Royal Institution of Great Britain, Albemarle Street, London, and has frequently been exhibited by the author and others at discourses given in the lecture theatre of the Institution.

if a secondary coil of fine silk-covered copper wire of great length was wound over the primary, the interruption of the primary current was accompanied by the production of a transitory but high electromotive force in the secondary circuit sufficient to create an electric spark between its terminals when brought near together (see Plate 8). The history of the development of this induction coil and the mode of construction adopted in making large spark coils, such as those of Ruhmkorff, Apps and others, has been fully described by the author in a book entitled *The Alternate Current Transformer*, first published in 1888.

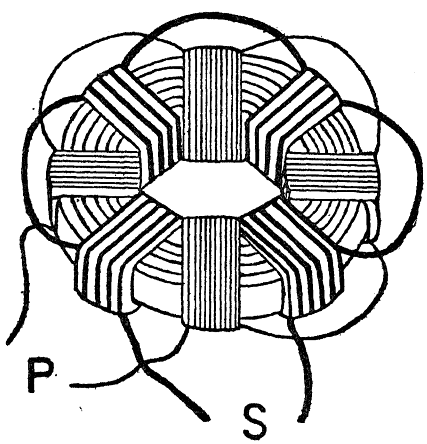
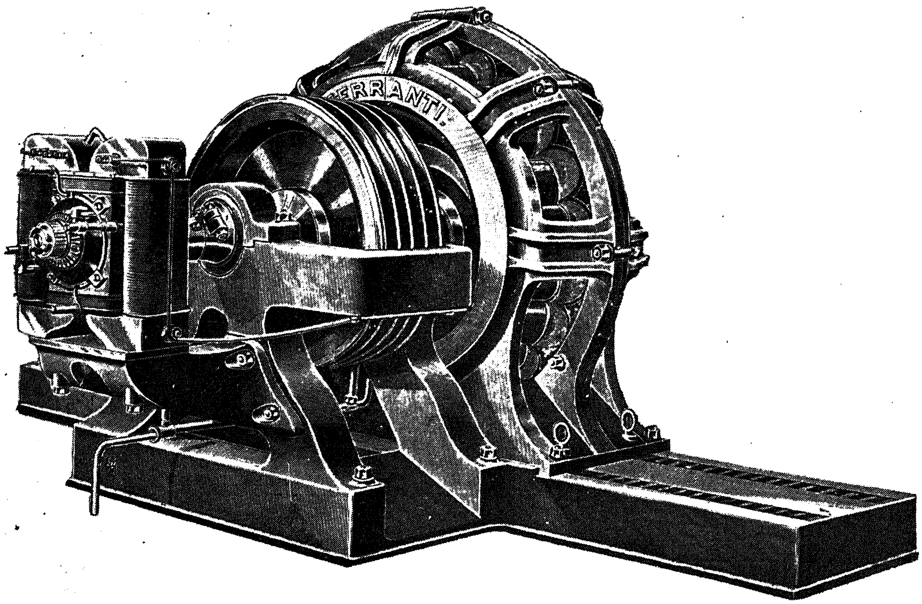


FIG. 12.—A Diagram illustrating the Construction of an Alternate Current Transformer. Two circuits P and S of insulated wire are wound in coils on an iron ring formed of thin iron sheets bound up in a bundle so as to form a ring of laminated iron.

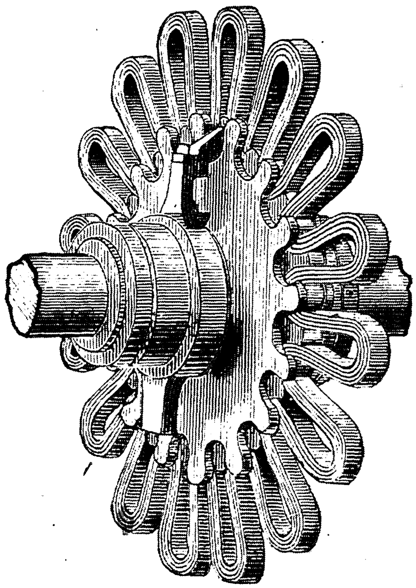
It was evident before long that, if an induction coil was constructed as above described, with two circuits, one of a few turns of wire and the other of many turns of wire wound on a laminated iron core, and if an alternating current was passed through one coil, it would create an alternating current in the other coil. Moreover, a discussion of the theory of the instrument showed that, if the current in the coil of few turns was a strong current generated by a small electromotive force, it would create in the coil of a large number of turns a feeble current, but of high electromotive force. Hence, by such a device we can transform electric energy and from a strong alternating current produce a feebler one, but of high voltage; or, *vice versa*, from a small current generated at high electromotive force produce a strong current at a correspondingly decreased voltage. In this form the induction coil is called an alternate current transformer (see Fig. 12).

When we transmit electric power to a distance by sending a current through copper wires, the power given to the circuit is measured by the product of the current reckoned in amperes, and the electric pressure at the sending end measured in volts and by a numerical factor called the

PLATE 7.



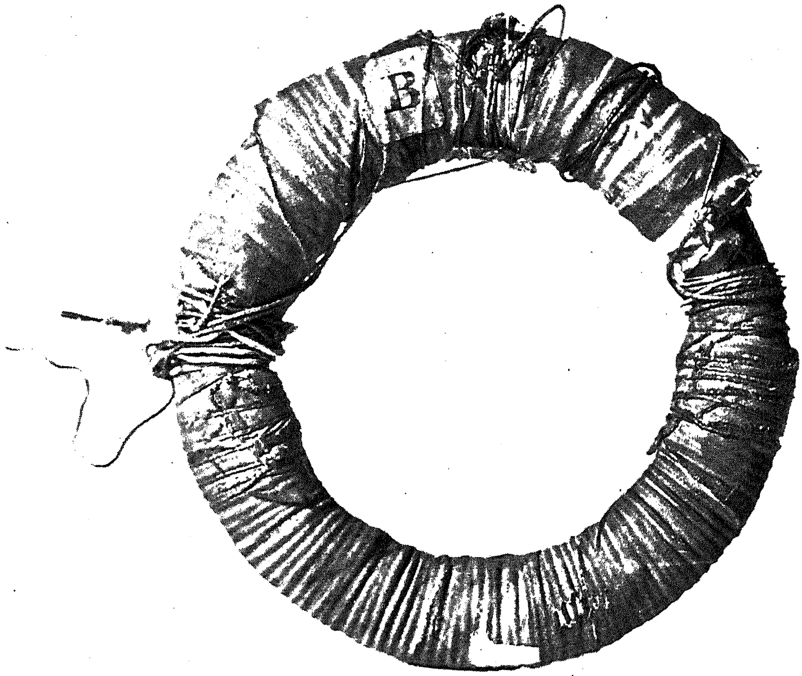
View of a Ferranti Alternator for generating an alternating current of electricity or one flowing to and fro in its circuit. A direct-current dynamo, which supplies the electric current for exciting the field magnets of the alternator, is fixed on the same shaft as the revolving armature of the alternator.



The Armature of the Ferranti Alternator built up of coils formed of copper strip. (See page 123.)

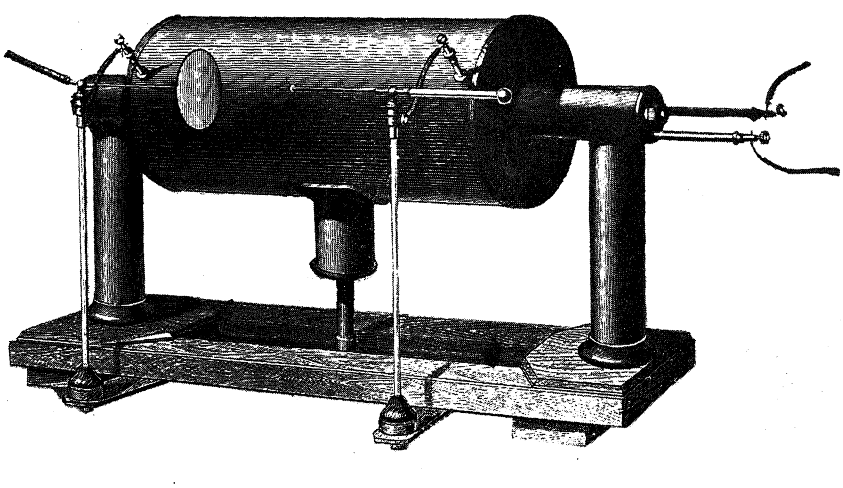
[*To face page* 128.

PLATE 8.



[*Photographed by Miss K. M. Reynolds by permission of the Royal Institution.*

A Photograph of the Iron Ring wound over with two Cotton-covered Copper Wires with which Faraday made his great discovery of the induction of electric currents, viz., that the starting or stopping of a current in one of the wires creates a brief secondary or induced current in the other wire. This historical relic is carefully preserved at the Royal Institution of Great Britain, Albemarle Street, London. It is the parent of all subsequent induction coils and transformers. (See page 127.)



A View of Mr. Spottiswoode's Large Induction Coil made by Mr. Apps in 1876. This coil is preserved at the Royal Institution of Great Britain, Albemarle Street, London. When first made it could give a spark between its secondary terminals 42 inches in length, resembling a miniature flash of lightning. The secondary circuit consists of 280 miles of silk-covered copper wire wound in sections. The spark could pierce a block of glass 3 inches thick. (See page 128.)

power factor, which is unity for direct currents and a little below unity for most alternating currents. A certain amount of this power is dissipated as heat in the supply wires, and this waste is measured by the product of the *square* of the current transmitted in amperes, and by the so-called electrical resistance of the wires reckoned in units, called the ohm. It is, therefore, evident that, to reduce this useless waste of energy in transmission, we must either keep the current small or else use wires of small resistance. This last course necessitates employing thick, and therefore costly, conductors.

It is, therefore, obviously an advantage to transmit electric power at high pressure by means of relatively small currents; but in general it is not convenient or safe to utilise electric currents at high pressure. Thus it would be very dangerous to introduce to a dwelling house electric supply wires between which there was an electric pressure of 10,000 volts. In fact, the Board of Trade would not allow it. The proposal, therefore, to supply electric energy from supply stations for domestic electric lighting at once raised the question of a safe and economical pressure of supply.

In the case of direct electric currents it is not quite an easy matter to transmit at high electric pressure and utilise at low pressure. By the use of the alternating current transformer it is, however, an extremely simple matter, and hence, in or about 1882, when public electric supply began to be furnished, the relative advantages of direct and alternating currents were hotly debated by electrical engineers. Mr. Edison, who had foreseen that the domestic use of electric energy for power as well as light would become important, advocated the use of direct-current supply, because of the greater facilities at that date for using it by small motors, and for some other reasons; but others, recognising that the use of direct currents imposed serious limits on economical transmission, turned attention to alternating currents. For a time electrical engineers were divided into opposite camps. Amongst those who early recognised the advantages of alternating current (A.C.) working as against direct current (D.C.) transmission were Mr. Ferranti in England, the Westinghouse Company in the United States, and Messrs. Ganz of Budapest.

In 1882 two patentees, Messrs. Lucian Gaulard and J. D. Gibbs,

obtained patents for alternating current distribution by means of transformers having their primary coils connected in series. This method, however, is not practicable, and their British patent was subsequently held, in 1888, to be invalid by a judgment of Mr. Justice Kekewich. Their plan was to connect the primary circuits of a number of induction coils in series and send through the circuit an alternating current under high electromotive force. They then thought that from the secondary circuits of each coil alternating currents could be drawn off and utilised as required. They did not foresee that changing the current taken from the secondary circuit of any one transformer affects the electromotive force set up in the secondary circuits of all the other transformers.

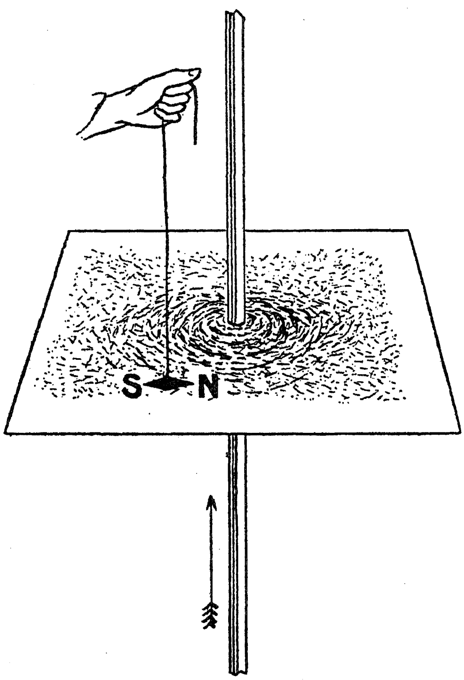


FIG. 13.—Circular Lines of Magnetic Flux round a vertical straight wire conveying an electric current in the direction of the arrow. The lines of flux are rendered visible by sprinkling iron filings on a card through a hole in which the wire passes. The iron filings arrange themselves in circular concentric lines round the wire, and a compass needle held just above them sets itself tangent to these circular lines of flux, thus indicating the magnetic force due to the current.

The reason for this is as follows:—Every electric circuit possesses two qualities (1) electric resistance and (2) electric inductance. In virtue of the first, energy is dissipated or transformed into heat in the circuit; in other words, the current makes the conductor hot, and this heat is useless for most purposes. In the next place the circuit stores up energy in consequence of its inductance or electric inertia. We know that we cannot set a heavy mass such as a motor-car or train, in quick motion instantly. We have to impart energy to it gradually. Again, we cannot bring it to rest instantly, but have to withdraw its energy of motion by degrees. This is said to be due to the mass or inertia. In

the same manner an electric circuit possesses inertia, and we cannot establish or destroy in it a strong electric current instantly.

The exact explanation of this is found in the fact that, when an electric current flows in a wire, it creates round the wire a magnetic field, the lines of flux being closed loops which embrace the wire (see Fig. 13). Hence, if we consider a single closed circuit, the attempt to start a current in this circuit brings into existence a magnetic field the lines of flux of which are linked with that of the electric circuit. But in consequence of Faraday's Law of Induction this introduction of lines of flux into a circuit creates in it an electromotive force. It is easy to prove that this self-induced electromotive force opposes in direction the impressed electromotive force which is creating the current. Hence there is an obstacle to the increase of the current which is only gradually removed. It also follows that, when the current begins to die away, there is a self-induced electromotive force due to the withdrawal of lines of magnetic flux which tends to prolong or continue the current. In short, the electric inertia or inductance of the circuit is due to the existence of these self-linked lines of magnetic flux.

When we send through a circuit an alternating electric current the combined effect of resistance and inductance is that the current never rises to the same strength it would do if the circuit did not possess inductance.

Supposing that we place parallel and close to each other two circular circuits and send through one of these an alternating current, it is easy to show that the induced secondary alternating current in the other circuit will be nearly in opposite phase; that is to say, will flow at any moment in an opposite direction to the primary current. Each current makes its own self-embracing magnetic field in step with itself, and, therefore, the magnetic field of the secondary current tends to reduce that due to the primary current. In other words, the production of a secondary current in the adjacent circuit tends to reduce the inductance of the primary circuit.

If we wind on an iron ring two separate spiral circuits, as in the case of the Faraday ring, and keep one of those circuits open—that is, the outer ends not joined together by a conductor—then the other circuit possesses

a certain degree of inductance. If, however, we connect together the ends of the secondary coil and permit a current to be generated in it, then the reaction on the primary circuit reduces the inductance of the latter, and the electromotive force supplying the primary current will cause more current to flow through the primary circuit.

Accordingly, it is clear that it is not possible to work a number of transformers in series like water-mills placed in series on the same stream, because the attempt to take current from the secondary circuit of any

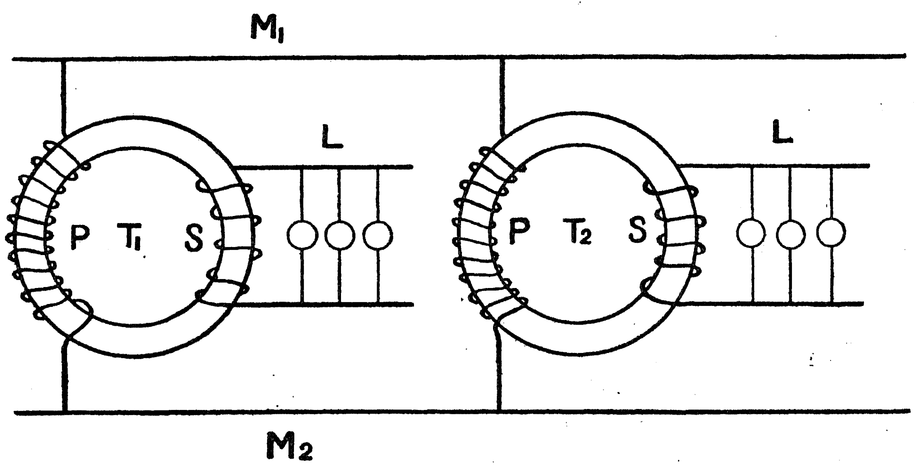


FIG. 14.—Alternate Current Transformers arranged with their primary coils P in parallel between two high-tension mains M_1 M_2 between which a high alternating voltage or electric pressure is maintained. The secondary circuits S of each transformer are connected to wires between which a number of electric lamps L are arranged in parallel. By this mode of working each electric lamp can be turned on or off without affecting the rest of the lamps.

one transformer increases the current through all the primary circuits of all the others.

About 1885, however, it became clear that transformers can be worked independently if the different primary circuits are arranged in parallel between two mains kept at constant high pressure, these primary circuits being joined across from one main to the other like the rungs of a ladder between the two side pieces, whilst the secondary circuits of each transformer are isolated. A system of parallel working of transformers was accordingly devised by three Hungarian inventors,

Messrs. Zipernowsky, Deri and Blathy, of Budapest (see Fig. 14). They constructed their transformer by winding up two coils of insulated wire into circular coils, and they bound these coils in close contact by winding them over with iron wire, so as to give it the shape of a lifebuoy or air cushion. The iron wire afforded a path of high permeability for the resultant lines of magnetic flux. The number of turns of wire on the primary and secondary circuits were so arranged that the transformer stepped down voltage in the ratio of ten to one. They constructed an alternator capable of supplying electric current at a pressure of 1,000 volts, and the transformers were designed to reduce this pressure to 100 volts on the secondary side.

A number of these transformers had their primary circuits supplied with current at 1,000 volts, when arranged in parallel on the alternator. Incandescent lamps were then placed in parallel on the secondary circuit of each transformer (see Fig. 14), and it was found that lamps could be turned on or off on any one transformer without affecting those on any other.

An experimental plant of this kind, brought to England in 1885 by Mr. Zipernowsky, of Budapest, was erected and tested at the Inventions Exhibition at South Kensington, London, by the author. Two transformers were used, each of 10 h.p. These were constructed to reduce electric pressure from 1,000 volts to 100 volts. They were, therefore, called *step-down* transformers. The transformers were arranged with primary or fine wire circuits in parallel at the far end of two wires, 800 yards long. At the other end an alternator supplied a current at a voltage of 1,000 volts. The transformers reduced this to 100 volts, with a 10 to 1 increase of current. Incandescent lamps were connected across the secondary terminals to provide a load on each secondary circuit. The author tested the working of this arrangement, and found that each transformer operated quite independently of the other. Also, the full load efficiency of transformation was quite as high (92 per cent.) as that of any dynamos then in use. From and after that date the use of step-down transformers to enable electric current to be transmitted at high voltage and used at low voltage was definitely adopted.

It having been thus demonstrated that the alternating current trans-

former was a fairly efficient energy-transforming device, an incentive was supplied to invention, and Messrs. Ferranti, Mordey, Kapp and others devised various types of transformer. These were classified by Dr. Kapp into *core* and *shell* transformers.

In the first type some form of iron ring, generally of rectangular shape and section, is built up by overlaying thin sheets of soft iron separated from each other by varnish or enamel. It is necessary to

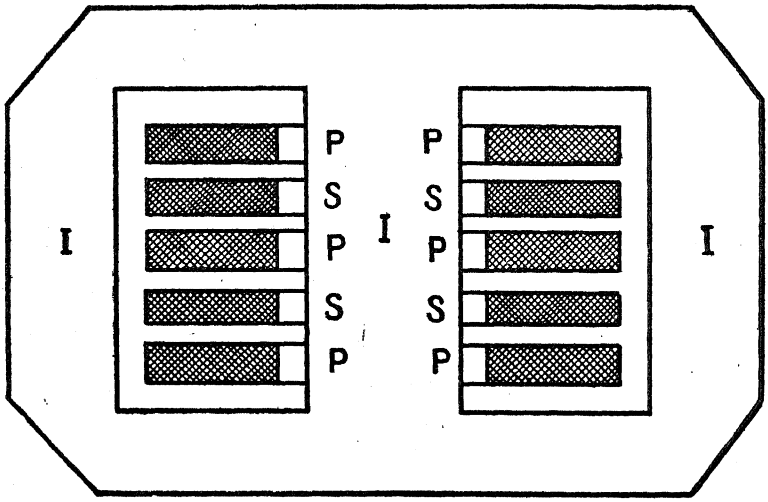


FIG. 15.—Section of a Shell Type of Alternate Current Transformer. The section of the primary coils P and secondary coils S is shown, and these are wound round the middle web of a number of superimposed sheet iron plates I which have two holes or windows stamped out of them.

build up a laminated core in this manner to stop the waste of energy due to the production of eddy electric currents which would take place if the iron core were solid.

In a core transformer the primary and secondary circuits are wound up with cotton-covered copper wire wound in sections on bobbins or formers, and these are then slipped on to the core. Such transformers are generally built to step-down voltage in a ratio, say, of 10 : 1 or 50 : 1 (see Fig. 15).

In the case of very high pressure transformers the completed transformer is placed in an iron box or drum filled up with highly insulating

resin oil. This keeps moisture from the cotton insulation, and preserves from breakdown.

In the Mordey transformer the coils are rectangular in shape, and the primary and secondary coils are overlaid with a shell of laminated iron formed of stampings of thin sheet iron (see Figs. 16 and 17).

In the Berry transformer, which is a more recent type, the primary and secondary coils are wound up into cylindrical coils, which are separated

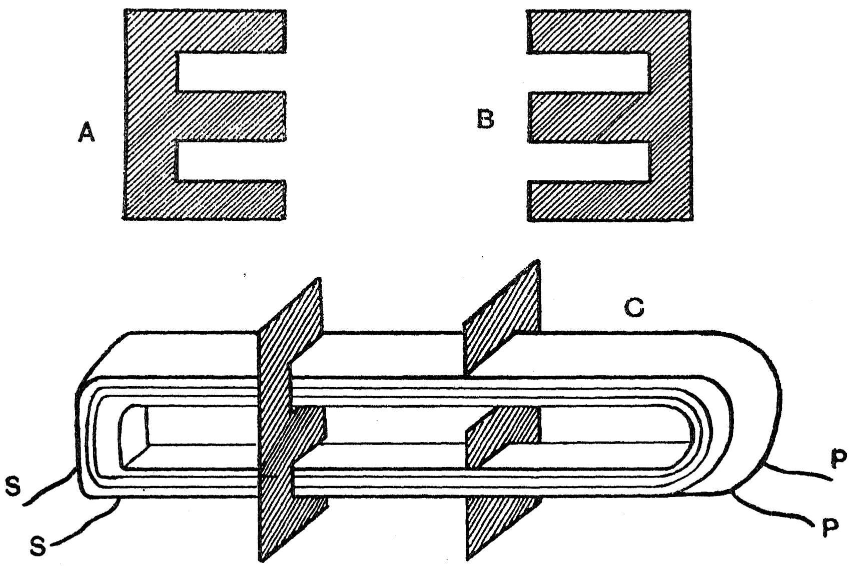


FIG. 16.—Mode of building up a Shell Type of Alternate Current Transformer. The primary coils P and secondary coils S are wound over each other and then surrounded by an iron jacket formed by slipping in E-shaped iron plates on each side and packing in as many as possible. The shaded parts are the iron plates.

by a micanite tube. The core is built up of stampings of thin iron in the shape of rectangles, one side of which passes down the central aperture of the coils, and the opposite side up on the outside (see Plate 9, page 136).

In addition to these forms of closed iron circuit transformer, others were made with incomplete cores.

Mr. Swinburne devised in 1891 a form called a Hedgehog Transformer, in which the core consisted of a bundle of iron wires which were splayed out or bent over at the ends.

Important questions then arose as to the efficiency of these various types.

In 1892 the author began an extensive series of tests, after first investigating carefully the various methods of measuring alternating current power which had been suggested. The results of these tests were communicated to the Institution of Electrical Engineers in November,

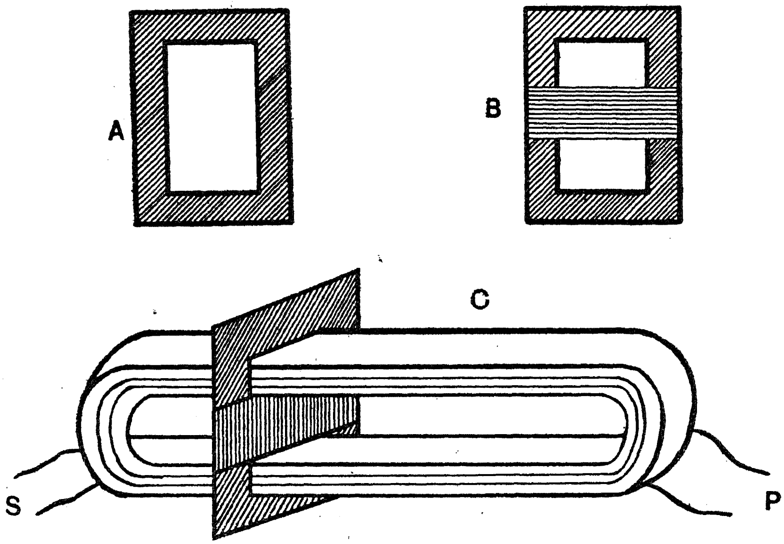
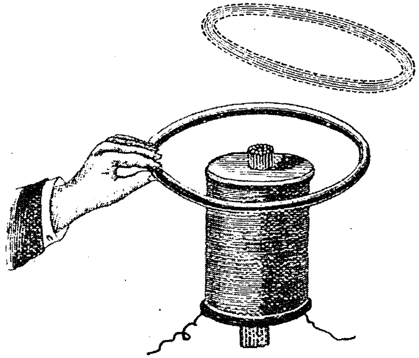


FIG. 17.—Another mode of building up the Iron Core in a Shell Type (Mordey) of Alternate Current Transformer. In this case rectangular iron plates are slipped over the coils and a transverse plate put through them, and as many as possible just packed in so as to surround the coils with iron. The iron plates are the shaded portion. The object of thus surrounding the coils with iron is to facilitate the production of magnetic flux which embraces and perforates each coil.

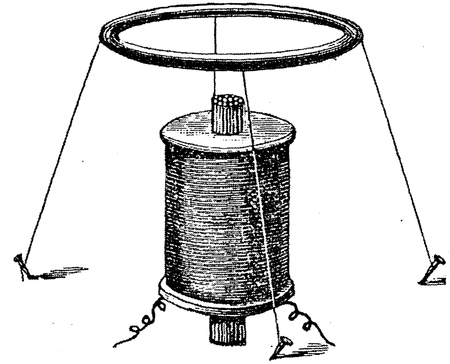
1892, in a long paper entitled "Experimental Researches on Alternate Current Transformers," which gave rise to great discussions.

The sources of energy waste in transformers are three, viz., those due to the resistance of the copper wire circuits, called copper losses, and those due to local electric currents set up in the iron core and the dissipation of energy involved in repeatedly reversing the direction of magnetisation of the iron core. These two last are called the core or iron losses. The loss due to magnetic reversals is called the hysteresis loss.

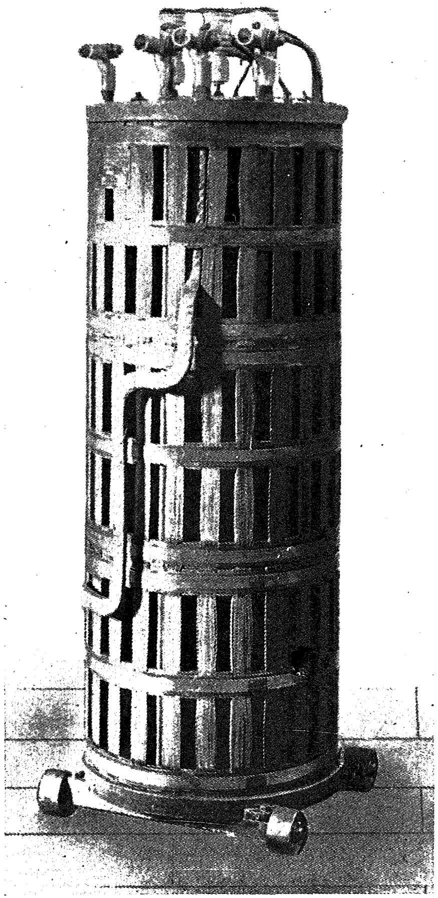
PLATE 9.



A Copper Ring held over the pole of an Alternating Current Electromagnet is strongly repelled and jumps up in the air when released.

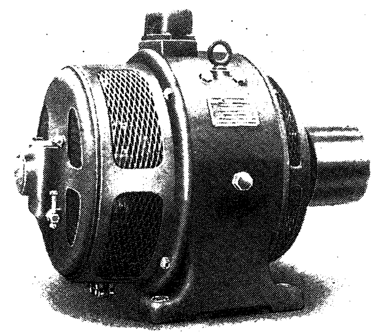


A Copper Ring tethered by strings floating in the air over the pole of an Alternating Current Electromagnet.



[By permission of the British Electric Transformer Co., Ltd.

A View of a Berry Type of Alternate Current Transformer.



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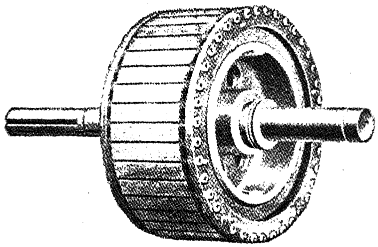
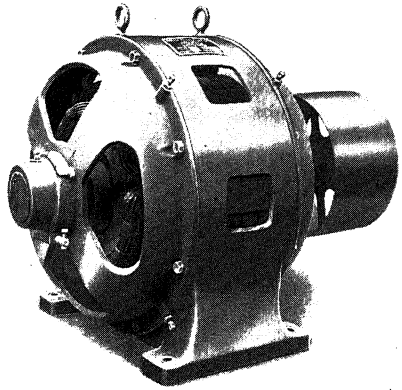
An Alternating Current Repulsion Motor. (See page 143.)



[*By kind permission of the Metropolitan Vickers Electric Co., Ltd.*

The "Squirrel Cage" Rotor or revolving part of a Three-phase Induction Motor.



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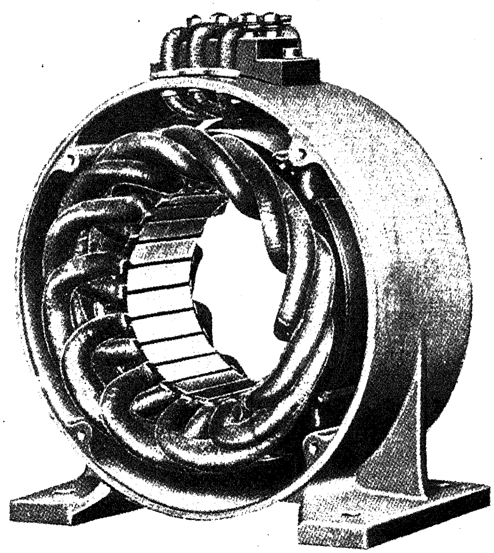
A General View of a Three-phase Alternating Current Induction Motor. (See page 146.)



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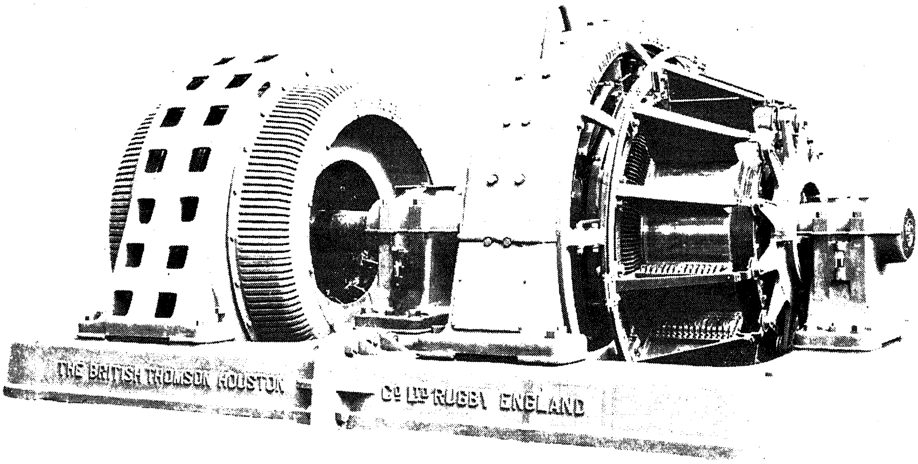
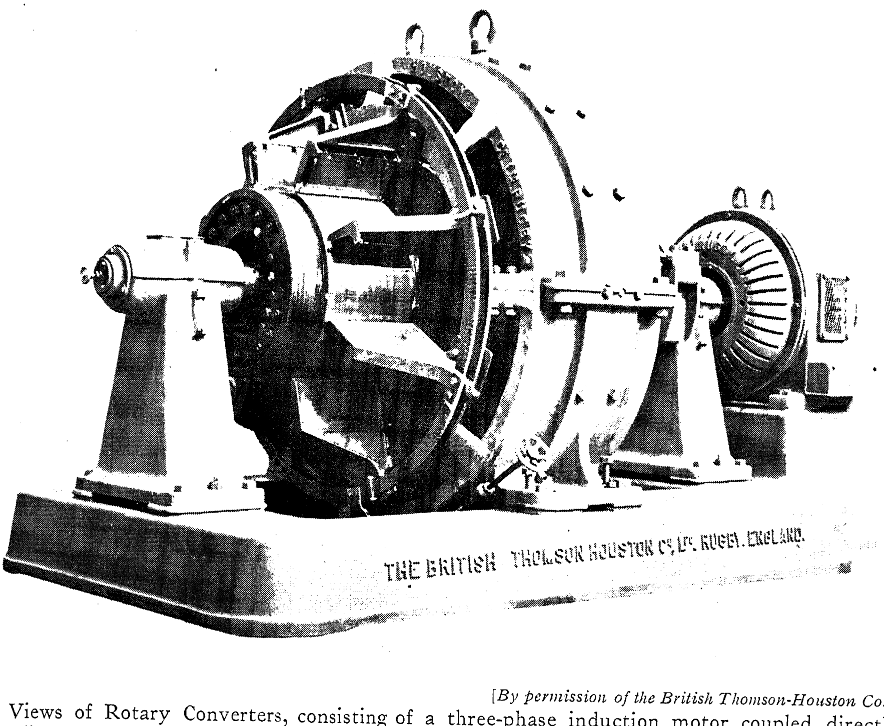
The Stator or stationary part of a Three-phase Alternating Current Induction Motor with rotor removed to show the arrangement of stator coils. (See page 146.)

PLATE II.

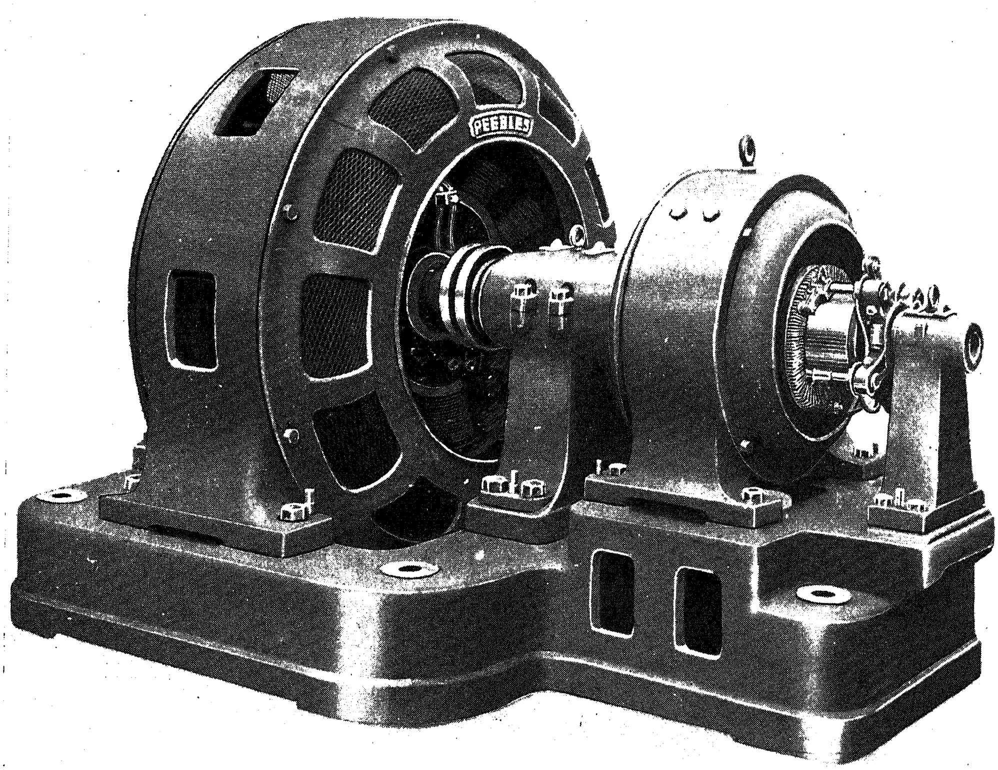




[*By permission of the British Thomson-Houston Co., Ltd.*

Two Views of Rotary Converters, consisting of a three-phase induction motor coupled directly to a direct-current dynamo. The three-phase motor receives three-phase alternating currents from some distant generating station, and is used to drive the direct-current dynamo to generate direct current for lighting or traction purposes. (See page 147.)

PLATE 12.



[*By permission of Messrs. Bruce, Peebles & Co.*

An Alternator for generating an Alternating Current of Electricity. A direct-current dynamo is coupled on the same shaft (right-hand side) for producing the current required to excite the field magnets of the alternator.

[*To face page* 137.

In the transformers made between 1882 and 1892, not sufficient attention was given to the magnetic quality of the sheet iron or steel used in making the cores. But soon after 1892 manufacturers of iron gave the subject close attention and succeeded in producing brands of pure iron having remarkably small hysteresis loss. In particular, an iron alloyed with a small percentage of silicon was found to be of great value for transformer cores. The result of tests made by the author in 1892, and at a later date, was to show that efficiencies of 95 to 96 per cent. at full load were obtainable in large transformers.

In process of time great advances were made in building alternating current transformers for very high voltages. In 1890 and 1891 Mr. Ferranti built transformers for reducing voltage from 10,000 to 2,000 volts, and later on as electric transmission of power developed, transformers were built in the United States for pressures as high as 100,000 volts.

The application of such instruments will be dealt with in Chapter V.

Alternating current transformers are usually called static transformers because all parts of such an appliance are stationary. It essentially consists of three circuits, viz., two copper wire electric circuits in which electric current flows, and an iron magnetic circuit in which magnetic flux exists, the three circuits being interlinked.

The simple explanation of the operation is that the primary alternating current in one electric circuit produces an alternating magnetic flux in the iron circuit, and this again generates an alternating electric current in the secondary electric circuit.

The transformer is called a step-up or step-down transformer according as it raises or lowers voltage, whilst at the same time the current output is correspondingly lowered or raised.

In a closed magnetic iron circuit transformer, that is one in which the iron core forms a complete ring, we may say, approximately, that the step-up or step-down ratio is the same as the ratio of the number of turns of wire in the two electric circuits of the transformer.

The theory and methods of design of alternating current transformers were dealt with by the author in his book on *The Alternate Current Transformer*, and by many other writers since, such as Dr. Gisbert Kapp and Mr. Hobart.

Before describing what are called rotary transformers, we must deal briefly with the invention of the electric motor.

Soon after the invention of the electromagnet it was seen that its attractive power might be made to create in masses of iron a reciprocating or else rotary motion, but as long as the source of electric current was limited to a primary battery in which zinc is consumed, the electric motor remained quite uneconomical as a source of power in comparison with a steam engine using coal for the production of steam. The question assumed a new aspect after the invention of the Gramme dynamo machine. It was then found that this machine could not only produce electric current when the armature was rotated by mechanical power, but that if an electric current from another dynamo was sent into it, rotation of the armature was produced. This is said to have been accidentally discovered at an electrical exhibition in Vienna in 1873.

The result was a general recognition that the dynamo electric machine is a "reversible engine," which means to say that it can effect the transformation of energy in both directions, converting mechanical power into electric power or *vice versâ*. Moreover, the efficiency in the two directions is not very different. Hence all improvements in the machine used as a dynamo were also improvements in it used as a motor.

Again, it followed that by coupling together a pair of dynamos electrically, that is, joining their collecting brushes by a pair of copper conductors, we were put in possession of the means of transmitting mechanical power to a distance with an energy waste or loss which was under control and not extravagantly large.

Let us consider, for instance, the simple case of two shunt-wound D.C. dynamos with drum armatures having their brushes connected by a pair of copper wires. If we apply mechanical power to the shaft of one machine and rotate the armature the bars or wires are forced to cut across the lines of magnetic flux of the field magnets. This generates in them an electric current which in part is transmitted to the distant machine acting as a motor. This current passes in part through the field coils and produces a magnetic flux in the air gaps. Also it passes in part through the armature conductors. A conductor in which there is an electric current when placed transversely in a magnetic field, experiences a

mechanical force pressing it across the field. Hence the armature is caused to rotate. We have, therefore, three directed things related to one another, viz., magnetic flux or field; electric current in a conductor; and motion produced in that conductor. These quantities are all at right angles to each other and related in direction in a certain way.

The author gave, in 1885, a rule for connecting them which has always since been called "Fleming's Hand Rule," as follows:—

Hold the fore-finger, middle finger and thumb of the right hand in such fashion that they are mutually perpendicular to each other (see Fig. 18). Then make the following associations: Let the direction of the *F*ore-finger denote the direction of a line of magnetic *F*orce or *F*lux, the direction of the m*I*ddle finger the direction of the *I*nduced current, and the direction of the thu*M*b the direction of the *M*otion of the conductor. Then motion of the conductor parallel to itself in the direction of the thumb in a field whose direction is that of the fore-finger will result in the production of an induced current in the direction of the middle finger. This rule holds good for dynamos. A corresponding rule holds good with regard to the *left* hand for motors. In the latter case the passage of a current through a conductor in the direction of the middle finger, when placed in a magnetic field, the direction of which is indicated by the fore-finger, will result in the conductor being urged to move parallel to itself in the direction indicated by the thumb.

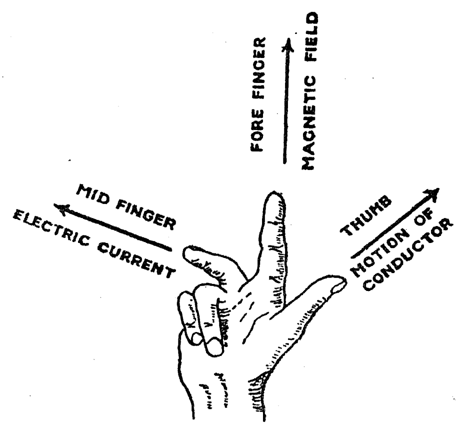


FIG. 18.—Fleming's Hand Rule. If the *F*ore-finger represents the direction of the magnetic *F*ield and the thu*M*b the direction of the *M*otion of the conductor parallel to itself, then the m*I*ddle finger will indicate the direction of the *I*nduced current.

In accordance with Faraday's Law of Induction the electromotive force (E.M.F.) created in a bar of a certain length when moved transversely to itself with a certain velocity across a magnetic field of a given strength is numerically equal to the product of the length, the velocity, and the field strength when measured in appropriate units.

Thus a bar having a length of 100 centimetres moving with a velocity of 2,000 centimetres per second in a magnetic field having 10,000 lines of flux per square centimetre, would have produced in it an absolute electromotive force of 2,000 million units, or 20 volts, since 100 million absolute units of E.M.F. are equal to 1 volt.

As regards motors the rule is similar. The mechanical force urging a conductor of a certain length conveying a current transversely across the lines of a magnetic field is equal to the product of length, field strength and current.

Supposing, then, that the dynamo has an efficiency of 80 per cent., and that two similar machines are coupled together. The motor will have nearly the same efficiency. The combination of the two will therefore have an efficiency of 80 $\times$ 80 per cent., or 64 per cent. But we have to consider the loss in the conductors. This is under control because we can give the conductors what resistance we please by adjusting their section.

Suppose we arrange to dissipate 10 per cent. of the supplied power in conductor loss; we can still transmit more than 50 per cent. of the power applied to rotate the dynamo and recover it as mechanical power on the shaft of the motor. Suitable design of dynamo, motor and conductor leads will increase this percentage considerably.

Hence, as soon as the dynamo had been proved to be an efficiently reversible engine in or about 1872 or 1873, the theory of the electric motor began to be carefully studied. Corresponding to the three types of self-excited dynamo there were the series, the shunt, and the compound wound motor depending on the way in which the field magnets were wound and excited, whether by the whole current or part of the current supplied to the motor. Each type possesses certain advantages. The series wound motor has a large starting torque, that is to say, it exerts a large rotary power on its own shaft immediately the current is sent into it, and it responds readily in speed and power to changes of current.

The shunt wound motor, on the other hand, must have its field excited before the current is sent through its armature. The reason is, that this armature when rotating in a magnetic field produces an electromotive force which opposes and holds back, to a certain extent, the current which would otherwise flow through the armature from the source of external

electromotive force. If, then, the magnetic field does not exist there would be such a rush of current through the armature that its circuits would be destroyed. Accordingly, a device called a "starter" is necessary, which secures that, on switching on, the magnetic field of the motor shall be created first, and then the current gradually increased through the armature as it gathers speed. The shunt wound motor has the property that it maintains a nearly uniform speed if the work it is called upon to do is varied.

The provision of electric current from supply stations, which began soon after 1882, stimulated the manufacture of small motors for driving fans, vacuum cleaners, and other domestic machinery, and the use of large electric motors for driving all kinds of machinery in works and factories became general as soon as that public supply was extensively increased in the early "nineties."

One of the arguments usually employed in support of the use of direct currents as opposed to alternating currents was, that the former enables small motors to be worked off direct-current lighting supply circuits. At that time the alternating current motor had hardly been developed, but its progress must now be traced.

It has already been explained that in the Edison system of electric supply by direct currents, it was arranged that a number of direct current (D.C.) dynamos at the station having the same voltage should pump their electricity into one common pair of copper bars called "bus bars," from which the general supply could be furnished. This is called parallel working. When public electric supply was first suggested it was the common opinion that alternators could not thus be worked in parallel, and even in the early alternating current supply stations it was never attempted.

But Dr. John Hopkinson, in 1883, theoretically proved that it was possible, and public demonstration of this was soon after given.

Let two identical alternators be connected electrically in parallel, but driven by separate engines not too well governed and arranged, to send their respective currents at the same voltage into a pair of bus bars. Hopkinson then showed that if these machines are started in step with each other, then they will control each other in phase and keep in step

in such fashion that if one machine tends to get ahead of the other in phase it will take more load and be slowed down, whereas if it lags in phase it will be a little relieved of load and, therefore, be accelerated by its engine. It follows from this that if one machine lags behind the other by 90° in phase it will be converted into a motor and be driven by the other machine, acting as a dynamo. An alternator so acting is called a single-phase alternating motor. The drawback to its use is that if loaded too much it will fall out of step with the driving machine and then stop and have to be started again in step. Also its field magnets have to be excited by a direct current, and its speed as a motor is dependent on the frequency of the current, that is, the number of complete oscillations or periods per second, and upon its number of field poles. It is, therefore, called a synchronous motor, that is, one keeping exact time. Nevertheless, it is unsuited for many purposes. On the other hand, an ordinary series wound direct-current motor can be used as an alternating current motor, provided that the field magnets are built, not with solid iron, but of laminated iron or strips to avoid the production of wasteful electric currents in the iron. The reason it can be so used is because the direction of rotation of a D.C. series wound motor is independent of the direction of the current flowing through it. If we reverse this direction we reverse the direction both of the magnetic field in the air gap and of the current in the armature winding and, hence, the force rotating the armature is still in the same direction.

A series wound D.C. motor with laminated iron field magnet is, therefore, called a commutator alternating current motor, and in modified form is practically used. Another kind of alternating current motor, called a repulsion motor, was developed from curious phenomena connected with an alternating current electromagnet, which were discovered by Professor Elihu Thomson and also by the author. In 1884 the author noticed that a copper disk suspended by a thread when placed in the interior of a circular coil of wire traversed by an alternating current always set itself, if free to turn, in a direction with its plane perpendicular to the plane of the coil.

Professor Elihu Thomson found in 1887 that a sheet of copper held above the pole of an electromagnet, with core made of a bundle of iron

wire and coils, traversed by an alternating current, was powerfully repelled (see Plate 9, page 136).

He exhibited numerous experiments to illustrate this fact, which were amplified and shown by the author in public at the Crystal Palace Electrical Exhibition in 1889. Also at the Royal Society of Arts, London, in May, 1890, and in a Friday evening discourse at the Royal Institution of Great Britain in March, 1891. A very striking experiment may be shown as follows :

A large alternating current electromagnet is constructed of a bundle of fine iron wires about 18 inches long and 4 inches in diameter. This is wound over with about three layers of cotton-covered copper wire, No. 14 size, and an alternating current of some 30 or 40 amperes sent through it. Around the magnet, about three-quarters of the way up, is placed a shelf, and on this rests a thick copper ring. On switching on the current the ring jumps up into the air, and if constrained by strings from flying away to one side it will, on falling back, float in the air above the magnet pole.

This effect is called electromagnetic repulsion, and it is due to the inductance of the ring circuit.

Since the magnet coils are traversed by an alternating current, the magnetic flux proceeding from the pole is an alternating one or rapidly reversed in direction. This alternating flux passes through the copper ring and produces in it a powerful alternating current. Owing to the inductance or electric inertia of the ring this current is out of step with the alternating electromotive force in the ring and, therefore, out of step with the magnetic flux from the pole. It is easy to show that the result is to subject the ring to a series of forces which are alternately pushes and pulls. But the pushes are more powerful than the pulls and, hence, on the whole the ring is repelled from the magnetic pole.*

Professor Elihu Thomson utilised this fact in an ingenious manner to construct what is called a repulsion motor, in which a number of coils wound on an armature of drum type with commutator and the two

* See Elihu Thomson, " Novel Phenomena of Alternating Currents," *Electrical World* of New York, May 28th, 1887. See also J. A. Fleming, " On Electromagnetic Repulsion," *Journ. Roy. Inst. of Great Britain*, March, 1891, and *Journ. Roy. Soc. of Arts*, May 14th, 1890.

brushes connected by a wire are successively repelled when the field magnets are excited by an alternating current and, hence, create rotation in the shaft to which they are fixed.

The simple series wound alternating current motor is never used in practice because it has a high inductance and sparks much at the brushes.

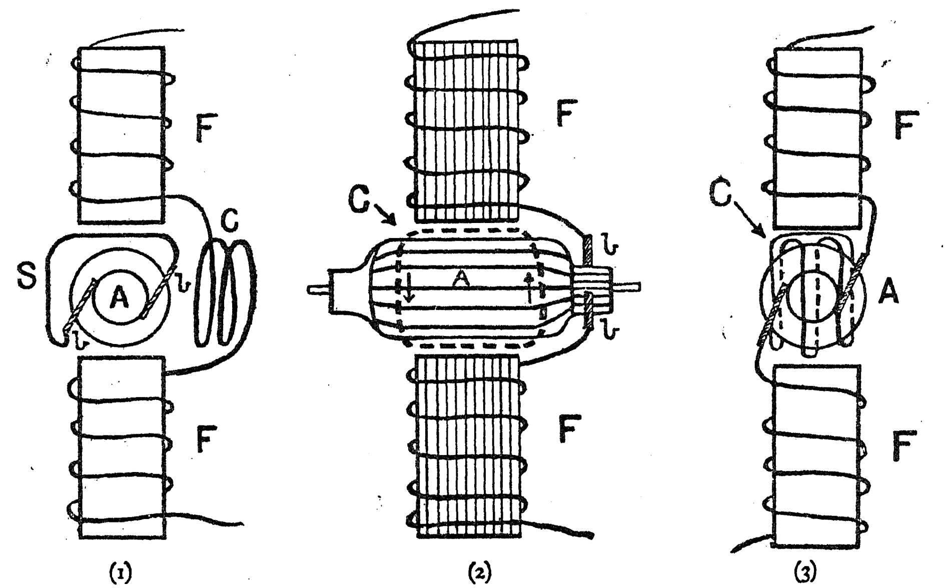


FIG. 19.—Diagrams illustrating the Winding and Circuits of a Compensated Series Alternating Current Electric Motor. F F are the field magnets, which are made, not of solid iron, but of bundles of thin iron sheets with paper or varnish between them to prevent the production of wasteful electric eddy currents in the metal by the alternating current flowing through the wire windings placed on the iron cores. A is an ordinary drum-wound armature and commutator. In diagrams (2) and (3) the current is shown flowing through the field coils and armature in series, and the compensating coil C is self-closed. In diagram (1) the current flows through the field coils and compensating coil in series, and the armature coils are short-circuited. In both cases the armature A is set in rotation when an alternating current is supplied to the motor.

It also has a low "power factor," which means that the alternating current through the motor is much out of step with the electric pressure or voltage at the terminals, and is, therefore, relatively an inefficient work-doing current. It can be improved by surrounding the rotating armature by a coil called a compensating coil, which produces a magnetic field at right angles to that produced by the series coil field magnet winding.

We can also achieve the same result by joining the brushes on the commutator by a short thick wire and arranging the compensating coil in series with the field magnet winding, but with its magnetic axis at right angles. The two modes are indicated in the diagrams in Fig. 19.

The combination of a repulsion motor and a compensated series motor gives us a type of commutator alternating current motor invented by Winter and Eichberg, and also by M. Latour. In this last type of A.C. motor there are two pairs of brushes on the commutator at right angles to each other. One pair is short-circuited by a thick wire. The other pair take current from the secondary circuit of a transformer, the primary coil of which is in series with the coils of the field magnets. The alternating current motor in every form labours under the disadvantages of greater bulk and generally greater cost per horse power exerted, compared with the continuous current motor.

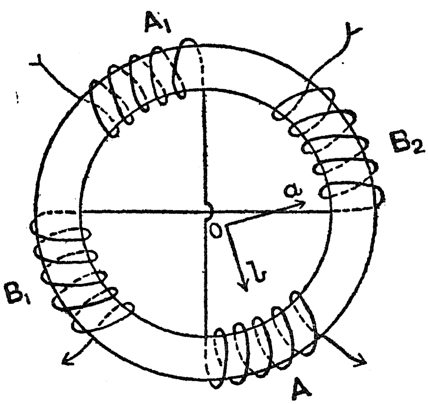


FIG. 20.—A Diagram showing one method of producing a Rotating Magnetic Field. On a ring of laminated iron are placed pairs of coils A A_1, B_1 B_2, which are respectively joined in series. The coils A A_1 are so connected that when a current flows through them it creates in the interior space within the ring a magnetic field in the direction, say, of O*a*. The other pair of coils B_1 B_2 are so joined up that when a current flows through them it will produce a field in the direction O*b*. If then two alternating currents are sent through these two circuits which differ in phase by 90 degrees, they will produce a magnetic field which rotates like the hand of a clock.

There are two other kinds of alternating current motor, called asynchronous, or induction motors, which involve the use of two or three-phase alternating currents producing a rotating magnetic field.

We construct a ring of thin iron bands bound up, and put upon this ring four coils at equidistant intervals, like the coils on a Gramme armature. One pair of diametrically opposite coils are joined up in series so that when an electric current is sent through them they will magnetise the two halves of the ring in opposite directions and therefore produce a north pole at the end of one diameter and a south pole at the other.

Hence, in the central air space there will be a magnetic field running across the ring. If this current is an alternating current the field in the air space will be an alternating field or perpetually reverse in direction. Let the other pair of diametral coils be now traversed in the same manner by another alternating current differing in phase from the first by 90°, both currents being provided by a two-phase alternator made as shown in Fig. 8. The conjoint effect of these two alternating magnetic fields in the interior of the ring, whose directions are at right angles to each other and whose phases differ by 90°, is to produce a nearly steady magnetic field which continually rotates like the hands of a watch in one direction or the other (see Fig. 20).

This method of producing a rotating magnetic field by the use of two alternating currents differing in phase by 90° seems to have occurred independently to several persons, viz., Professor G. Ferraris, Mr. Nikola Tesla and Mr. Von Dolivo Dobrowolsky, between the years 1885 and 1888. The two latter inventors developed this idea in the construction of many remarkable forms of rotating field motor.

Furthermore, it was seen that by the use of three-phase alternating currents differing in phase by 120°, similar results might be obtained.

If we place in such a rotating magnetic field a pivoted bar of iron, or better still, a drum of laminated iron on which are placed self-closed coils of copper wire, we can construct a two- or three-phase induction motor as it is called.

One type, called a squirrel cage induction motor, is made as follows: A number of thin iron rings are built up with paper between them into a hollow laminated iron cylinder. The disks have teeth cut in their inner edge, and in the grooves so formed in the cylinder coils of insulated wire are laid in such fashion that when traversed by an electric current the inward projecting teeth between form a series of alternate north and south magnetic poles. This part of the machine is called the stator, because it stands still, or is fixed. On the stator there are either two or three sets of coils joined in series according as the motor is a two- or three-phase one, and these coils are respectively supplied with two- or three-phase alternating currents from an alternator made as already described (see Plate 10, page 136).

The coils are so placed and connected that the result is to produce a rotating magnetic field in the interior of the stator. From the alternately placed north and south poles bunches of lines of magnetic flux radially proceed which march round the interior of the ring.

We then place in the interior a drum built up of iron disks on the circumference of which are placed bars of copper all connected to two copper rings at both ends. These bars are let into longitudinal grooves cut on the drum surface parallel to the axis. This portion is pivoted on a central axis and is called the rotor because it can revolve. When the stator is supplied with two- or three-phase currents and produces a revolving magnetic field, the lines of this field move laterally across the copper bars of the rotor and induce in them currents which cause the rotor bars to be moved parallel to themselves, and hence rotate the rotor.

A pulley can be fixed to the axis of rotation and the arrangement will then act as a motor. It has the advantage that there are no brushes nor commutator and hence no sparking. The speed with which it runs is dependent in part upon the load and is not fixed entirely by the frequency of the stator current (see Plate 10, page 136).

Such a polyphase induction motor is of use in coal mines and other places where a motor liable to spark would be dangerous.

By winding the rotor with certain forms of circuit the ends of which are brought to three insulated metal rings fixed on the rotor shaft, we can introduce into the rotor circuits resistance coils placed outside the machine. The connection between these resistances and the rotor coils is made by means of copper gauze or wire brushes which press against the slip rings.

These resistances are called starting resistances because they enable us to give the motor power to start under a load and also give us power within limits to regulate the speed.

Between 1888 and 1900 these polyphase induction motors were perfected and largely applied as explained in Chapter V. in the electrical transmission of power, by alternating currents. The direct coupling of a polyphase (generally three-phase) induction motor with a direct current generator gave us a rotary transformer which has rendered possible most of the large electric supply distributions established in the last twenty years (see Plate 11, page 137).

CHAPTER III

ELECTRIC LAMPS AND ELECTRIC LIGHTING IN THE LAST FIFTY YEARS

At the beginning of the nineteenth century Sir Humphry Davy had been provided at the Royal Institution in London with a large battery of voltaic cells for the prosecution of his electrochemical researches.* These cells consisted of copper and zinc plates placed in vessels containing acidulated water.

In 1808 he attached to the terminal wires of this battery two pieces of hard charcoal, and bringing the ends in contact he found that when slightly separated a dazzling arc of flame bridged the interval, and he thus produced what has since been known as the electric arc. Ordinary wood charcoal is not a very good conductor of electricity, and it was later on found that better results could be obtained by using rods cut from coke, especially the dense graphitic form of it which is left in gas retorts.

It was soon seen that these rods, being incandescent at the tips, consumed away by combustion in the air; the positive carbon wastes away about twice as fast as the negative.

The chief portion of the light is emitted from the incandescent tip of the positive carbon, which becomes hollowed out into a cup or crater. Hence the use of the electric arc as a source of illumination requires some mechanism for holding the carbon rods in line, bringing them together, separating them slightly, and then maintaining them at the right distance apart as they consume. Bringing the ends in contact and then slightly separating them is called "striking the arc," and keeping them at the right distance to maintain it is called "feeding the arc" (see Fig. 1).

* Sir Humphry Davy laid a request before the managers of the Royal Institution of Great Britain, on July 11th, 1808, that they would provide him with a large voltaic battery. As a result a battery of 2,000 cells was set up for him, and one of the earliest experiments made with it was the production of the electric arc on a large scale (see Dr. Paris' *Life of Sir Humphry Davy*); but it is probable that he first produced it on a small scale in 1801.

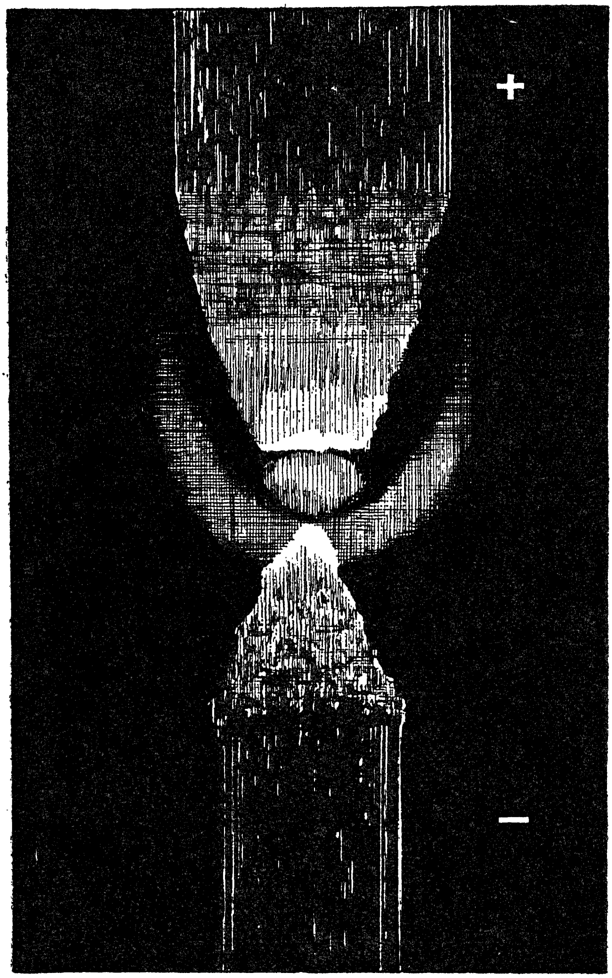


FIG. 1.—An Electric Arc formed between the ends of rods of hard graphitic carbon when these are made the terminals of a voltaic battery of at least fifty cells. The rod attached to the positive pole (marked +) becomes hollowed out at the tip and intensely hot. It is called the crater of the arc, and its temperature is 3,600° C.; 85 per cent. of the light emitted comes from the crater. The negative carbon becomes pointed and less hot. The flame which plays between the tips of the rods is incandescent carbon vapour. An electric arc can be formed either with a direct or with an alternating electric current.

If the carbons are drawn too far apart the electric current through the arc diminishes, and finally the arc is extinguished if they are separated more than a certain distance.

The electric arc, considered as a conductor, possesses the curious property that as the current through it increases the potential difference or electric voltage of the carbon rods decreases, and *vice versâ*. A curve so drawn that the vertical and horizontal distances of any point on it from a datum line and origin represents to scale the potential difference in volts, and the arc current in amperes, is called the *characteristic curve* of the arc. It is a downward sloping curve.

As long as the only source of electric current was a voltaic battery consuming zinc, the electric arc had no industrial use, but remained a scientific experiment, or at most, a source of illumination for scientific work on account of its cost. With the introduction of magneto-electric machines the position was altered and invention began to be directed to arc lamps.

J. B. L. Foucault was one of the first to devise a form of self-regulating arc lamp, and another form for lighthouse work was designed by V. L. M. Serrin, and a third by J. Duboscq.

The early forms of arc lamp were, however, clockwork mechanisms controlled by an electromagnet, and their expense and complication rendered them unsuited for street or public lighting.

The invention of the Gramme dynamo gave improved means for generating the steady electric current required for arc lighting, and the possibility of it was assisted by the introduction of moulded carbon rods of uniform quality. These were first produced in France in 1876 by F. P. E. Carré. Finely powdered coke, or better still, lampblack, obtained by imperfect combustion of certain oils, is mixed with tar or syrup into a paste and pressed by hydraulic presses through a die into rod form. These rods are dried and then baked in a furnace at a high temperature out of contact with air. The mixing material is carbonised and the result is a hard carbon rod of good conductivity. In some cases the rod is made hollow and the centre filled up with soft carbon. These rods are called "cored carbons." In other cases the rod is electrolytically coated with a thin layer of copper to improve the conductivity.

In 1876 Paul Jablochkov, a Russian officer passing through Paris, invented his electric candle, which was then considered to be a very practical solution of the problem of street arc lighting. He placed two moulded Carré carbons parallel to each other and separated them by a narrow layer of kaolin or porcelain clay. The carbons were fixed in a holder which allowed current to pass up one carbon, jump across the top and down the other carbon, thus producing the electric arc at the tip. To start the arc the carbons' ends were bridged across by a bit of soft moulded carbon.

To secure equality of combustion in the two rods an alternating current of electricity was employed (Plate 1, page 148). A number of such "candles" were worked in series, and for street lighting each lantern contained two or more candles with an electrical switch which, in case of one candle being extinguished, immediately switched over the current to a new one. Although this system received extensive trials in Paris and London and elsewhere, between 1877 and 1881, it was found uneconomical in the long run owing to the large number of half-burnt candles that accumulated, due to the extinction of the light either by wind or momentary interruption of the current.

When this happened the "candle" could not relight itself.

In 1878, C. F. Brush, in the United States, invented his high tension direct constant current dynamo already described, and a simple form of electric arc lamp to work with it. The lamp contained a fixed lower or negative carbon, which was carried in a holder. The upper or positive carbon was carried on a rod which was embraced by a loose ring. If this ring was tilted by lifting one side it gripped the rod and raised the upper carbon. The ring was lifted by a metal finger raised by the attraction of an electromagnet through the coils of which the currents for the arc passed. When the current was switched on the magnet lifted the ring, raised the upper carbon and struck the arc. If the current decreased or ceased, the upper carbon dropped again and re-established the arc.

An arc lamp with single series coil as above described has necessarily an irregular feed.

In the arc lamp designed to work on the Thomson-Houston arc lamp dynamo described in the previous chapter, the regulation of the carbons

was effected by a shunt and series coil, a method initiated by F. Von. Hefner Alteneck in 1878.

The arrangement may be briefly described as follows. The whole current supplying the electric arc passes through a cylindrical coil of insulated wire called the series coil. If a soft iron rod is partly introduced

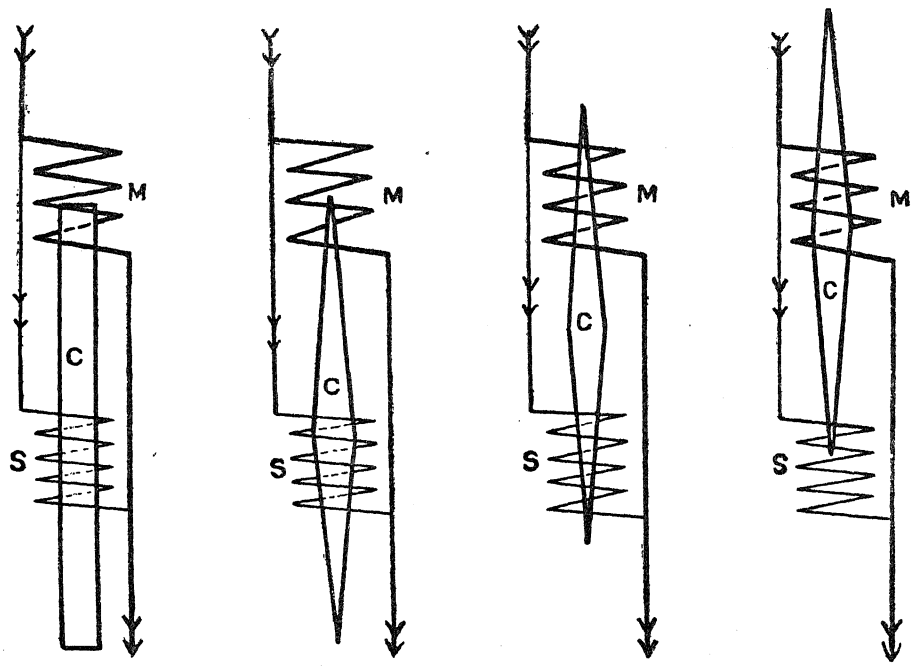


Fig. 2.—Diagrams illustrating the Mechanism of a Shunt and Series Coil Arc Lamp. C is an iron core, which may be a simple cylinder or else a double cone. M is a series coil through which the whole arc current flows, and S is a shunt coil, the ends of which are connected to the two carbon rods. The coils attract and move the core in opposite directions. When the current becomes too strong the coil M pulls up the core, to which one carbon rod is attached, and this lengthens the arc. When the current is too weak the coil S pulls the carbons together and shortens the arc.

into such a coil then, when a direct current flows through it, the rod is sucked or pulled into the coil. This can be made to actuate a mechanism which draws the carbon rods of the lamp slightly apart and starts the arc between their tips. The moment they are drawn apart there is produced a difference of potential or voltage between the carbons of about 40—50 volts or so, depending on the strength of the arc current (see Fig. 2)

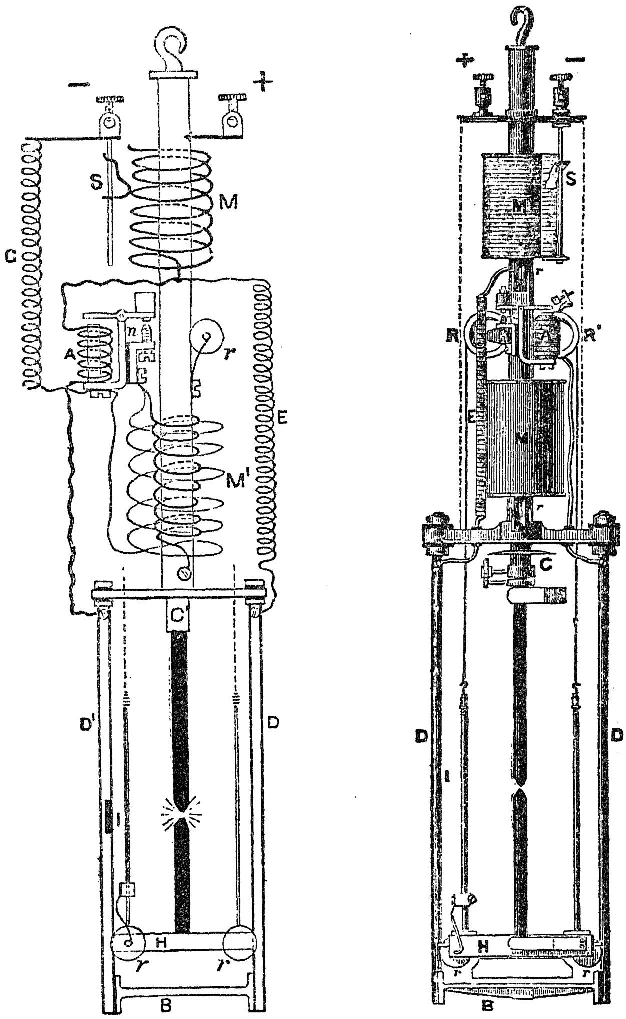


Fig. 3.—The Mechanism of the Pilsen Arc Lamp in use about 1882. The upper coil of wire M is the series coil. The iron core is inside the brass tube C which passes through the coils M, M′. M′ is the shunt coil. The upper carbon rod is attached to the iron core and moves with it. The black rods are the arc lamp carbon rods.

A coil of fine insulated wire has its terminals connected to the two carbons. This coil is called a shunt coil. Hence, when the tips of the carbons are in contact there is no potential difference between them and no current in

the shunt coil. When the arc is struck a current flows in the shunt coil. By means of the movement of an iron core sucked into this coil the carbons can be brought nearer together, so that the effects of the series and shunt coils on the arc are opposed. If the length of the electric arc increases above a certain amount the shunt coil draws the carbons a little nearer together. If the arc decreases in length this increases the arc current and the series coil draws them a little apart. The two coils therefore automatically adjust the arc and keep it constant in length as the carbons burn away. This shunt and series coil adjustment is employed in nearly every successful form of arc lamp.

Although a large amount of street arc lighting and lighting of railway stations, goods yards, open spaces, esplanades, and public buildings was carried out by means of open arcs made as above described, by means of improved arc lamps such as the Pilsen, Brockie-Pell, Crompton, Siemens Brothers, Thomson-Houston and improved Brush arcs between 1880 and 1890, yet there were certain drawbacks to it (Fig. 3). One of these was the necessity for re-carboning each arc lamp daily. The 10-ampere arc lamp required from 1—2 inches of arc lamp carbon rod per hour, the sizes in general use being 10 millimetre negative and 14 millimetre cored positive carbons. In a few cases magazine arc lamps were designed in which a store of carbon rods automatically replaced each other as they were used up. The cost of carbons is increased by the combustion due to the action of the oxygen of the air, which has free access.

Accordingly, about 1893, enclosed arc lamps were introduced by L. B. Marks. In this case the arc is formed inside a small nearly closed glass globe, and as soon as the oxygen is used up the arc remains in an atmosphere of nitrogen and carbon dioxide. The arc is longer and requires a higher voltage, about 80—90 volts, as compared with about 40—50 for the open arc, and the consumption of power for the same mean hemispherical candle-power is about 60 per cent. greater for the enclosed than for the open arc, but the carbons burn away much more slowly and last five to ten times as long.

In spite of these advantages the lower efficiency of the enclosed arc told against its extensive use.

The improvements introduced towards the close of the nineteenth

century in gas lighting, such as the Welsbach mantle and high-pressure gas burners, placed the open arc lamp at a still greater disadvantage in competition with gas.

The introduction of flame arc lamps gave, therefore, a new start to out-door arc lighting.

The flame arc lamp is one of the most efficient artificial lights in existence, but is only adapted for street lighting. It originated with H. Bremer, who, in 1899, patented the incorporation with the arc lamp carbon of the fluorides of magnesium, barium, calcium, strontium and other salts for the purpose of varying the tint of the light emitted and increasing the luminous efficiency.* Subsequently, the flame-producing salts were incorporated in the core of the carbon and serve to change the light from a bluish white to yellow or snow white as required.

These cored carbons give a long arc, but require only 40—45 volts per arc, and the power consumption is reduced from about 1 or 0·3 watt per hemispherical candle for open arcs to 0·4 or 0·25 for the flame arc. In the latter the light comes chiefly from the flame, and the two carbon rods are not placed in vertical line, but both slope downwards at a small angle, so that the light from the crater is projected downwards as well.

The flame arc is not suited for indoor lighting on account of the vapours emitted from the volatilised impregnating materials.

Bremer undoubtedly initiated a very important improvement in arc lighting, which has been developed by other workers in a manner which enabled arc lighting for a time to hold its place against high-pressure gas as an illuminant. Nevertheless, the flame arc has itself been dethroned from its position by the half-watt incandescent lamp.

We turn, then, to consider the development of incandescent electric lighting.

From the time when it was first found that an electric current produces heat in a conductor and can raise it to incandescence, if sufficiently refractory, inventors were attracted by the problem of producing a small

* H. Bremer obtained a British patent, No. 14704, July 17th, 1899, for "improvements in electrodes for arc lamps." He found that the oxides of metals incorporated with the carbon produced an infusible non-conducting ash which in time extinguished the arc. By using the fluorides of these metals he discovered that the slag then formed was liquid and dropped away from the arc without clogging the ends of the carbons.

unit of light for domestic purposes by means of the electric current. In the phraseology of bygone days this was called "dividing the electric light."

In nearly all cases the early attempts were made to use platinum or platinum-iridium wire as the heated material, because it was almost the only metal of very high melting point (about 1,700° C.) then obtainable. But all pure metals have a rather sharply defined fusing point, and it was not easy to bring a wire of platinum to brilliant incandescence without risking the melting of the wire.

Very many inventors attacked the problem, such as F. de Molyens in 1841, J. W. Starr in 1845, J. J. W. Watson in 1853, and W. E. Staite in 1848, but none of these inventors succeeded in making a practically useful incandescent electric lamp. Edison himself began to work with a platinum wire lamp in 1878, and devised ingenious arrangements for cutting off the current if the wire became heated nearly to its fusing point.

It gradually became clear to many workers that success would most likely be obtained by using carbon as the heated material, but this involved placing it in a vacuum or, at least, in a non-oxidising atmosphere. Starr, Sawyer, and Man and others had already endeavoured to make use of thin carbon rods for this purpose.

The problem was finally solved by Mr. T. A. Edison and by Sir Joseph Wilson Swan, the latter being ably assisted by Mr. C. H. Stearn (see Plates 2 and 3, pages 149 and 156).

In early attempts to make a carbon incandescent lamp inventors employed a piece of carbon in the form of a slender rod, and held this in clips attached to wires sealed through the walls of a glass bulb, which was then exhausted.

Sir Joseph Swan made such a lamp in 1878, and exhibited it at Newcastle on December 19th, 1878 * (see Plate 1, page 148).

Edison, however, successfully solved the problem when he recognised that the material to be heated must first be given a filamentary form, and then subsequently carbonised.

In his principal patent specification on this subject he proposed to

* Swan's fundamental British patent for the electric incandescent lamp is No. 18 of 1880, and claims the process of heating the carbon filament during the exhaustion of the bulb to extricate the occluded gases in it.

SIR JOSEPH WILSON SWAN, F.R.S.

1828—1914.

Co-inventor with Edison of the carbon filament electric lamp. He made numerous important inventions in photography and electrometallurgy, and in connection with the storage battery and other electrical inventions.

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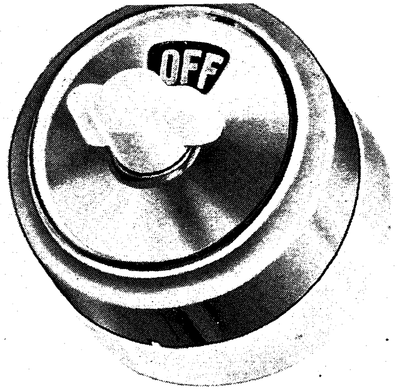

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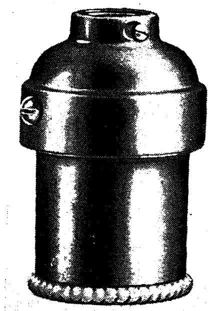
(1)



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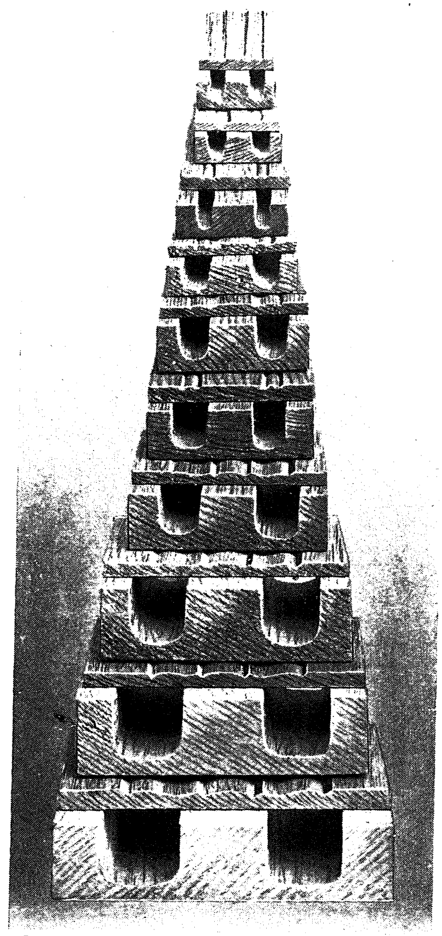

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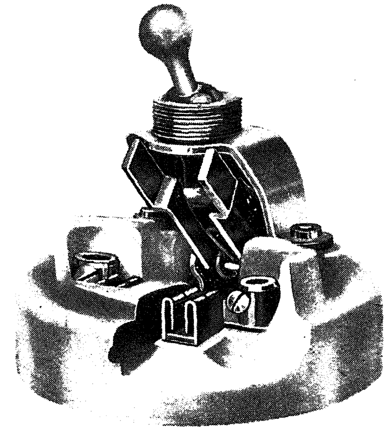

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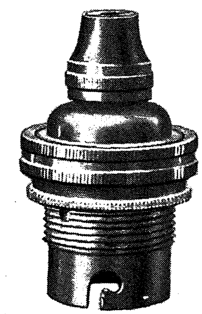


(5)

(1) An Electric Light Switch.
(2) An Edison Screw Electric Lamp Socket.
(3) Sections of Wood Casing for Electric Light Wiring.

(4) A Tumbler Electric Switch.
(5) A Bottom Contact (B.C.) Electric Lamp Socket.

[To face page 157.

use a loop of horse-shoe shape, formed by mixing lampblack and tar into a stiff paste and rolling it out into a filament, the ends of which were attached to two platinum wires. This "tar putty," as it was called, was then carbonised by heating it in a red-hot closed crucible or iron box, and the resulting carbon loop sealed into a glass bulb through the walls of which the platinum wires which held the loop were sealed.

The glass bulb was then exhausted of its air by an air pump, and the bulb sealed off.

Edison patented this process in the United States and in Great Britain in 1879.

The British patent (No. 4576 of November, 1879) gave rise to a large amount of patent litigation in Great Britain, with which the author was closely connected during the years 1886–1889, in which it ran on.

The owners of the British patent were the Edison and Swan United Electric Light Company, and in May, 1886, actions for infringement were brought against Messrs. Woodhouse and Rawson, and judgment was given in favour of the patent by Mr. Justice Butt, and this was upheld on appeal.

In 1888 a more hotly contested action was fought, nominally against Mr. W. Holland and the Jablochkov and General Electricity Company, but, in fact, fought by the Brush Electric Light Company.

The great point of contest was the sufficiency of the specification, and at one stage the plaintiffs had to make lamps with tar and lampblack as described in the specification, to show that it could be done. The expert witnesses for the Edison and Swan United Electric Light Company successfully established the practical sufficiency of the specification.

A matter on which there was much conflicting evidence turned on the answer to the question: What is a filament?

The first two claims of Edison's British specification were as follows:—

(1) An electric lamp giving light by incandescence consisting of a filament of carbon of high resistance made as described, and secured to metallic wires as set forth.

(2) The combination of a carbon filament within a receiver made entirely of glass, through which the leading wires pass and from which the air is exhausted for the purposes set forth.

In spite of the fact that the Edison experts and witnesses prepared tar putty filament lamps exactly as the specification prescribes, Mr. Justice Kay gave judgment against the specification. But his judgment was reversed by the Court of Appeal, and the case was not taken to the House of Lords.

The first commercially useful carbon filament incandescent lamps began to be constructed by Edison in 1880 (see Plate 1, page 148).* In these lamps a slip of a particular kind of bamboo cane was cut into very narrow strips and bent into a hair-pin shape. It was then carbonised in a closed crucible or box packed in coke dust or plumbago. The carbonised filament then had terminal wires attached to it, the junction or clip being electrolytically covered with copper to make a good low-resistance joint. These wires were sealed through the end of an inset tube into a pear-shaped glass bulb, and the bulb exhausted to a high vacuum by means of a mercury pump.

It was found by Sir Joseph Swan that it was necessary to heat the filament to incandescence during the exhaustion, and also to heat the glass bulb, so as to liberate all occluded and adhering gas.

Sir Joseph Swan, aided by Mr. C. H. Stearn, about the same time produced a similar lamp, using a carbonised cotton thread which had been previously parchmentised by treating it with sulphuric acid.

An important improvement was due to two inventors, Sawyer and Man, who patented a process subsequently called "treating." †

Any such material as bamboo or parchmentised thread or carbonised paper has minute structural defects which give rise to points of high resistance in it. The temperature, therefore, is abnormally raised at these points by the current, and tends to destroy the filament. If, however, the filament is previously heated several times to incandescence

* The first two of these lamps exhibited in London were brought over from the United States at the beginning of 1880 by Mr. E. H. Johnson. He requested the author to make arrangements for exhibiting them in action. The author accordingly obtained some seventy bichromate voltaic cells to supply the 100-volt electromotive force necessary, and showed the lamps working in a basement room at 11, Queen Victoria Street, London, E.C., where at that time the offices of the Edison Telephone Company, of London, were situated. They were shown to many people, and this was the first occasion on which Edison incandescent electric lamps of this type were exhibited in action in London.

† Sawyer and Man, acting through an agent, F. J. Cheeseborough, patented this process in Great Britain on November 28th, 1878—No. 4847.

in a hydrocarbon atmosphere, such as coal gas, the decomposition of the hydrocarbon deposits a layer of graphitic carbon upon it. This deposit takes place most thickly at any place in the filament which has high resistance, and therefore the highest temperature. Treating in hydrocarbon vapour, therefore, removes these defects, and unifies and lowers the resistance of the filament. In this manner the raw carbonised filaments can be rendered electrically identical.

Moreover, the carbon so deposited is graphitic and has a metallic lustre, and this has other auxiliary advantages. Carbon filament lamps of the above types began to be made in 1882 in large numbers.

Early in 1882 a limited company called the Edison Electric Light Company, of London, was formed to exploit Mr. Edison's inventions in electric lighting in London. The author was appointed, through the influence of the secretary of the company, Mr. Arnold White, scientific adviser to that company and retained in the same position after the amalgamation with the Swan Electric Lighting Company, forming the Edison and Swan United Electric Light Company. The first opportunity given to the public of seeing electric incandescent lighting on a large scale was at the Crystal Palace Electrical Exhibition, which was opened in the spring of that year.

Large exhibits were made by Edison, Swan, Maxim, and other inventors of incandescent lamps and, in particular, Edison showed all the details of his appliances for the public supply of electric energy by meter for domestic electric lighting.

Even after the lapse of thirty-eight years the writer has a clear recollection of the great novelty and beauty of this Edison exhibit at the Crystal Palace, including, amongst other things, a large, cone-shaped pendant electrolier, carrying a brilliant equipment of incandescent lamps, and a screen bearing an artificial vine in metal work, the grapes on which were represented by Edison glow lamps in glass shades of floral shape and various colours.

The author was, therefore, placed in an advantageous position for studying the physical phenomena of carbon filament lamps. It was soon found that in such lamps the interior of the vacuous bulb became blackened with use by a deposit of carbon, but a curious fact was noticed, that in

many cases there was a line of no deposit on the glass in the plane of the horse-shoe shaped carbon loop, either on one side or the other. This clearly indicated that under certain circumstances carbon atoms were shot off from the filament from some point in straight lines. About this time (1883) Mr. Edison made an interesting observation. He sealed into a lamp a metal plate placed between the legs of the carbon loop (see Fig. 4). This plate was carried on a wire sealed through the wall of the glass bulb. He noticed that when the filament was made incandescent by a direct current, a galvanometer or other current-detecting instrument showed a small electric current in a circuit connecting this plate with the positive terminal of the filament. On the other hand, in a circuit connecting the plate and the negative end of the filament, there was no sensible current. This effect was called the "Edison effect," but Edison gave no explanation of it, nor did he make of it any practical application.

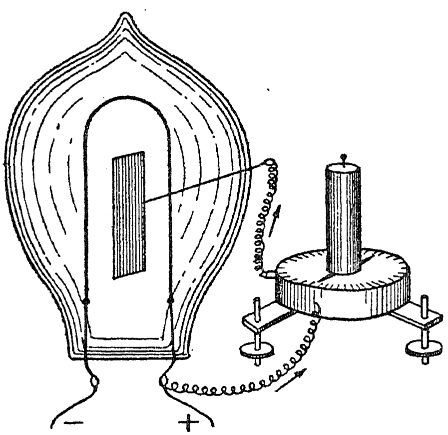


FIG. 4.—An Incandescent Carbon Filament Lamp with a metal plate sealed into the bulb for showing the "Edison effect." See also Chapter VII. of this book.

In the last chapter of this book it will be mentioned that the author some years later made an application in wireless telegraphy of an incandescent lamp, having a plate sealed into the bulb, which has developed into wonderful inventions in connection with that subject.

Returning then to the evolution of the incandescent or glow lamp, as it was called, Edison made his first lamps with bamboo filaments of such length that they gave respectively a light equal to eight, or sixteen, or thirty-two candles, as required, when current was supplied to the filament at a pressure of 110 volts. The power taken by them was at the rate of 3·5 to 4 watts per candle. In other words, the luminous efficiency was from 0·25 to 0·3 candle power (c.p.) per watt.

The lamps were arranged on circuits with the filaments of all of them

connected across between two conductors kept at some standard voltage, say, 110 volts (see Fig. 5).

Edison had carefully worked out before 1882 all the details of a complete system for the public supply of electric energy for lighting as described in Chapter V.

Each lamp was equipped with a metal screw collar and a bottom contact plate, which were in connection respectively with the ends of the filament. He designed a socket, into which the lamp screwed, and the act of so doing made the necessary electric connection with the two

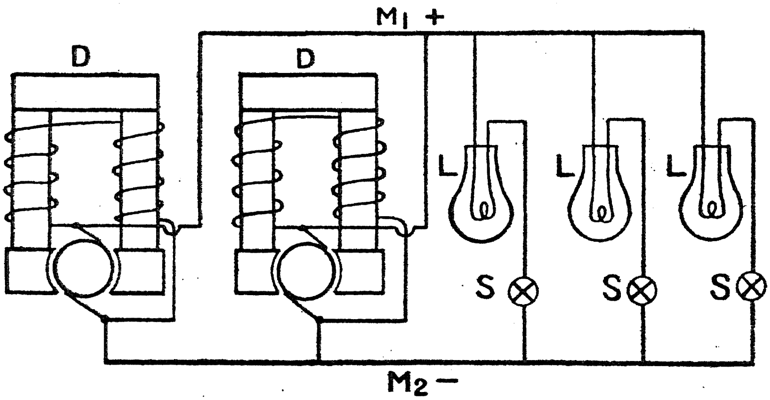


FIG. 5.—Incandescent Lamps L each in series with a Switch S, and placed in parallel between two Mains M_1 + and M_2 — kept at a constant voltage by Dynamos D also placed in parallel.

electric conductors brought to the socket. Edison also devised a complete system of electric wiring for houses, the insulated wires being laid in grooves or strips of wood called "casing" (see Plates 1 and 4, pages 148 and 157).

For underground distribution through streets he designed a system of iron tubes, in which were placed copper bars of semi-cylindrical section, which were insulated from each other and from the tube by a bituminous material forced into the tube when made fluid by heat. These are described more in detail in Chapter V.

He had also arranged a system of charging for the electrical energy supplied to the consumer by measuring the quantity of electricity given to any house circuit by means of the electrolytic deposit of zinc.

When a current of electricity flows through a solution of sulphate of zinc by means of two zinc plates immersed in it, zinc is dissolved off one plate and deposited on the other. The electrochemical equivalent of zinc, that is, the weight removed per ampere of current per hour, is 1·213 grammes. Hence, if a known fraction of the total quantity (say, $\frac{1}{1000}$) delivered to a consumer at a constant voltage of 110 volts is measured, we can calculate from the meter, reading the total electric energy supplied in any time (see Plate 5).

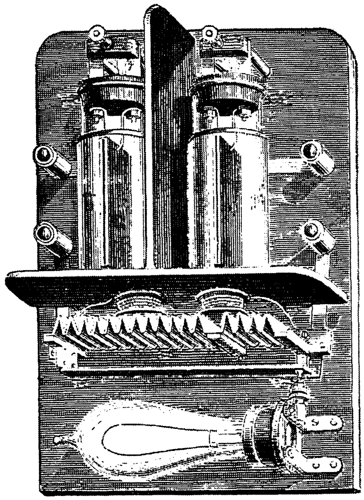
The unit employed in electric supply is *a kilowatt-hour*, or 1,000 watt-hours, which is called a Board of Trade Unit (B.T.U.). Thus, if a consumer uses an electric current of 10 amperes for 1 hour, delivered at 200 volts pressure, he has taken two kilowatt-hours or two Board of Trade Units from the supply. In Great Britain it was arranged that one B.T.U. should be supplied at a price of not more than 8*d*., and before the European War the charge was reduced in some places as low as ½*d*. per unit for heating and cooking. It has since risen to nearly its maximum permitted value again owing to the increased cost of coal and labour. Some types of modern electric house meter are described in Chapter VI.

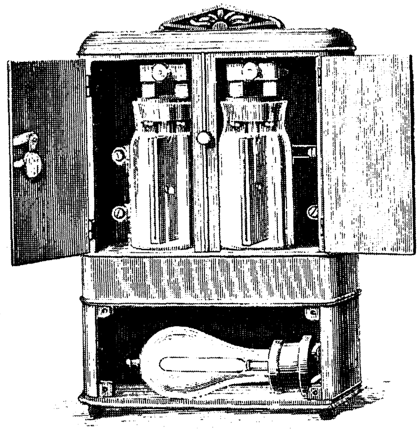
Soon after 1882 improvements began to be introduced into the manufacture of the carbon filament lamp. It was found that a structural carbon formed by carbonising a vegetable fibre was very liable to defects. Hence, a mode of producing a very uniform kind of filament, called a "squirted" filament, was invented.

The material called cellulose, represented by pure cotton-wool, is soluble in certain substances, such as a strong solution of zinc chloride. In this dissolved state it can be forced through a die or "squirted" into a very fine thread, and, after washing and drying, this thread can be cut into lengths and carbonised in a closed box in a furnace. Carbon loops of this material can then be "treated" or "flashed" by the deposit of carbon upon them by the Sawyer and Man process, and yield more uniform carbon filaments than any carbonised bamboo or woven thread.

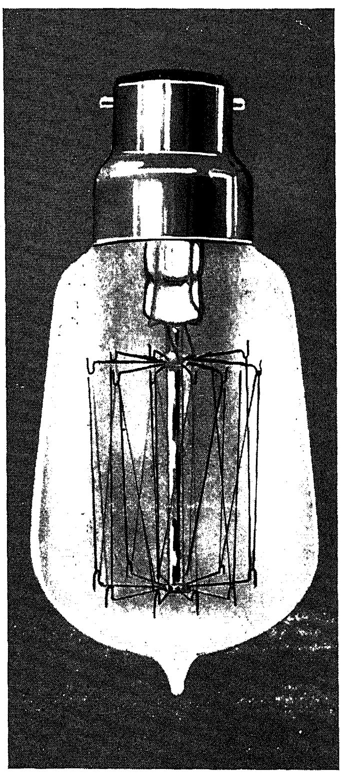
After the amalgamation of the Edison and Swan Companies in England in 1883 this was the process adopted for making carbon filament lamps.

PLATE 5

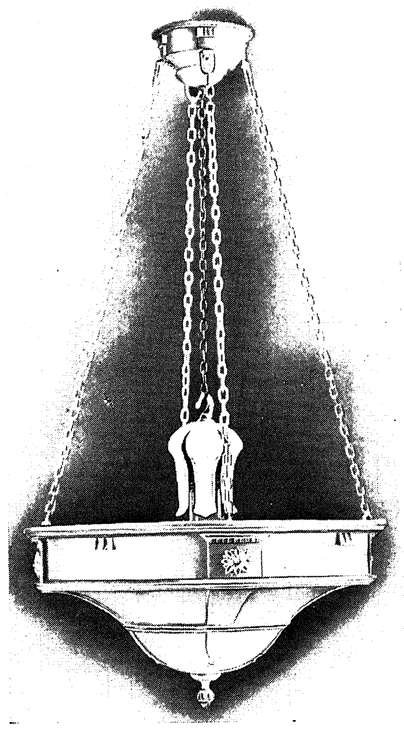




An Edison Electrolytic Zinc Plate House Meter as used 1882—5 for Metering the Electric Energy supplied for Electric Lighting. (See page 162.)



A Modern Drawn-wire Tungsten Incandescent Electric Lamp. (See page 165.)



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A Bowl Electric Fitting for Modern Tungsten Lamp Electric Lighting. (See page 169.)

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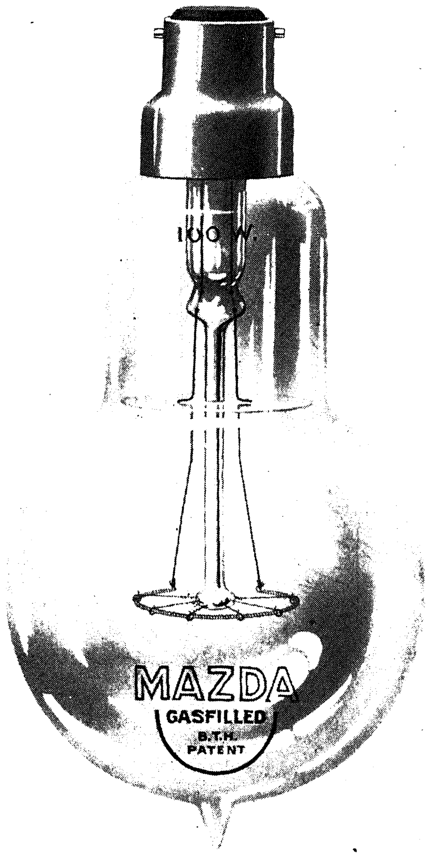
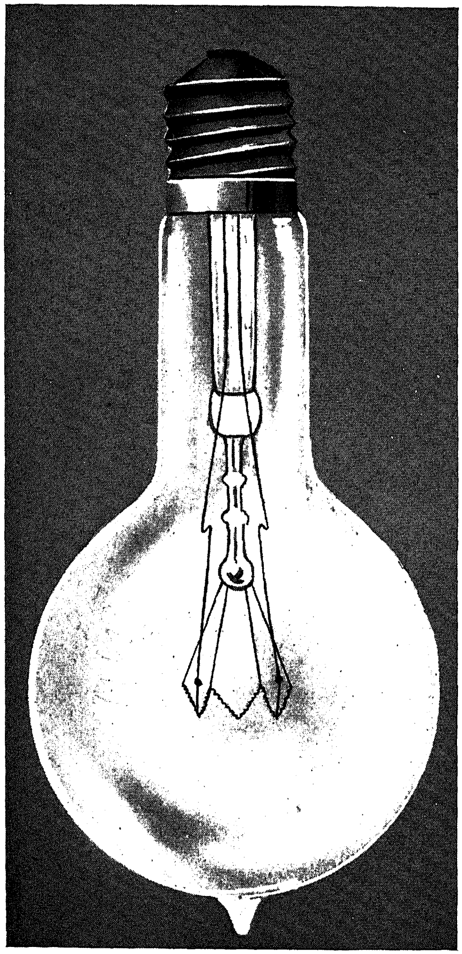
PLATE 6.





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Modern Drawn Tungsten Wire Gas-filled or Half-watt Lamps. (See page 166.)

[*To face page* 163.

The average duration or "life" of this carbon filament, apart from accidents, was about 1,000 hours.

The competition with gas as an illuminant brought about much scientific research, directed with the object of increasing the efficiency of the lamp and decreasing its manufacturing costs.

The great drawback in the case of carbon lies in its comparatively low volatilisation temperature and in its great affinity for oxygen at high temperatures.

When a refractory material is raised in temperature its radiation is at first non-luminous, viz., dark heat radiation. As the temperature rises, luminous radiation at the red end of the spectrum makes its appearance and shorter wavelength radiation is progressively emitted as the temperature rises. Carbon begins to volatilise or evaporate rapidly *in vacuo* at temperatures near the melting point of platinum at about 1,700° C. Hence, about 1,500° C. or 1,600° C. is the limit of temperature use for a filament of carbon. At this temperature the energy of the luminous radiation is not more than 3 per cent. at most of the total energy given to the filament. In the case of the electric arc, owing to the higher temperature of the crater, viz., about 3,500° C., the luminous efficiency is about 10 per cent. or 15 per cent. The problem of increasing the efficiency of the incandescent electric lamp was, therefore, closely connected with that of finding a material which could be raised to a higher temperature than carbon *in vacuo* without melting or evaporating. Platinum was ruled out because its melting point is only 1,700° C.

It was known that there were a number of metals of much higher fusing points, such as tungsten, tantalum, molybdenum, etc., but up to 1884 or 1885 these metals were chemical rarities and, although their salts and oxides or sulphides were in common use for various purposes, the preparation of the pure metals from them on a large scale had not been attempted.

It has since been found that pure tungsten has its melting point at 3,267° C. and its boiling point at 4,927° C., or a melting point not far below the temperature of the crater of the electric arc.

Meanwhile, another solution of the problem was suggested by H. W. Nernst in 1897. Non-metallic refractory oxides of metals, such as mag-

nesia, which is the oxide of magnesium, are very good non-conductors of electricity when cold, but if heated to a bright incandescence they become conductors, and an electric current passed through them will produce heat, and maintain the conductivity and incandescence. Nernst found that by using the oxide of magnesium mixed with oxides of rare metals, such as cerium, thorium, etc., and moulding the material into slender rods, he could make these rods conductive by merely heating them by the radiation from a white-hot platinum spiral, and that then an electric current passed through the rod would maintain it in vivid incandescence. Hence, he invented the Nernst electric lamp, which at one time had considerable vogue and use, but it was killed by the advent of the metallic filament lamp. The Nernst lamp comprised a slender rod or filament moulded out of oxides of rare metals and surrounded by a platinum spiral. The heating current was first sent through this spiral to heat the oxide conductor and then sent through the latter to make it incandescent.

The Nernst lamp gave a brilliant white light and was more "efficient" than the carbon filament lamp. The disadvantage was that it did not light up quickly but required ten or fifteen seconds or more to acquire its full incandescence. Also the socket and auxiliary arrangements were more complicated than in the case of the carbon lamp. The oxide heater had an iron wire resistance in series with it to compensate for its own reduction in resistance as the temperature rose.

The next advance was initiated by Auer von Welsbach, who also invented the gas mantle. He suggested the use of the refractory metal osmium for filaments, but a still more valuable improvement was made in 1903, when W. von Bolton produced the tantalum lamp. He succeeded in preparing the highly infusible metal tantalum in the form of wire, and with it, owing to its very high melting point, he made an incandescent lamp which required a power of only 1·5 or 1·6 watts to yield one candle-power. With this material glow lamps were made of small candle-power to work at a voltage of 110 or less.

The tantalum lamp was manufactured by Messrs. Siemens Brothers, and had a useful life of 600—800 hours, and an efficiency of 0·6 candle-power per watt expended in it.

But this, in turn, was replaced by the tungsten lamp of Just, Hanaman

and Kuzel. The difficulty at first was to produce this highly infusible metal in the form of wire. Originally, a process was employed which consisted in obtaining the metals in a colloidal condition in which extremely small metal particles are embedded in a gelatinous material. This is squirted into a filament and then dried and reduced to the condition of an aggregation of metallic particles welded together by passing an electric current through it. Later on methods were invented by Dr. W. D Coolidge for fusing the metal in an electric furnace, and drawing it into fine wire. The metal is first obtained in the form of powder by heating the oxide of tungsten in hydrogen gas.

The oxide of tungsten is prepared from a mineral called wolfram, which is a tungstate of iron and manganese, and also from an ore composed of calcium tungstate. Wolfram and other tungsten ores occur in large quantities in various places, particularly in Burma, British India, and has become of great value in steel tool manufacture owing to the discovery that a small percentage of it gives to steel a hardness which is not removed even at a red heat.

The tungsten powder is compressed in a mould into fragile rods which are then intensely heated in an electric furnace and gently hammered to compress and weld the particles together. The final result is to produce a rod of metallic tungsten, which is ductile but extremely infusible, and can be drawn into a wire of extreme fineness, elasticity and great tensile strength.

In the modern incandescent metallic filament lamp the material used is annealed drawn tungsten wire. After being prepared in the metallic or reguline form the metal is drawn down to the condition of a very fine wire through diamond dies. Owing to the fact that tungsten has a much less specific electrical resistance than carbon, viz., about five millionths of an ohm per centimetric cube as compared with 4,000 millionths of an ohm for carbon, a filament for giving the same candle-power, and working at the same voltage, has to be made thinner and longer when using the metal than when employing treated carbon. Many new problems of construction were therefore involved in the evolution of a practical metallic filament lamp having a bulb of about the same size as those used for carbon filaments (see Plate 5, page 162). In a 105-volt lamp of about 16 c.p., a length of some 24 inches of tungsten wire is employed.

This wire is zig-zagged over a sort of frame composed of a central glass rod with small projecting pins of wire radiating at both ends.

Some difficulty was found at first in making the metallic filament lamps in sufficiently small candle-power units, such as 10 or 16 c.p., especially as the usual voltage of supply had been raised from 100 or 110 to 200 or 240 volts in the case of most public supply stations, for economical reasons, by the time the tungsten lamp was on the market.

Tungsten lamps are now obtainable for working on all the standard supply voltages, 100, 105, 110, 200, 210, 220 or 240, and of candle-power as low as 10 for the lower voltages, and 16 to 32 or more for the higher. The luminous efficiency of hard-drawn tungsten wire lamps varies from 0·7 to 0·9 c.p. per watt, whereas that of the carbon filament lamp is only 0·25 to 0·3 c.p. per watt. Moreover, the tungsten drawn wire filament has a higher average life than the treated carbon filament. A peculiarity of the metallic filament lamp is that its resistance increases with rise of temperature, whereas the reverse is the case with carbon. Hence, on switching on a carbon filament lamp the current gradually increases as the filament heats up. In the case of the metallic filament lamp there is a rush of current through it at first, which gradually dies down.

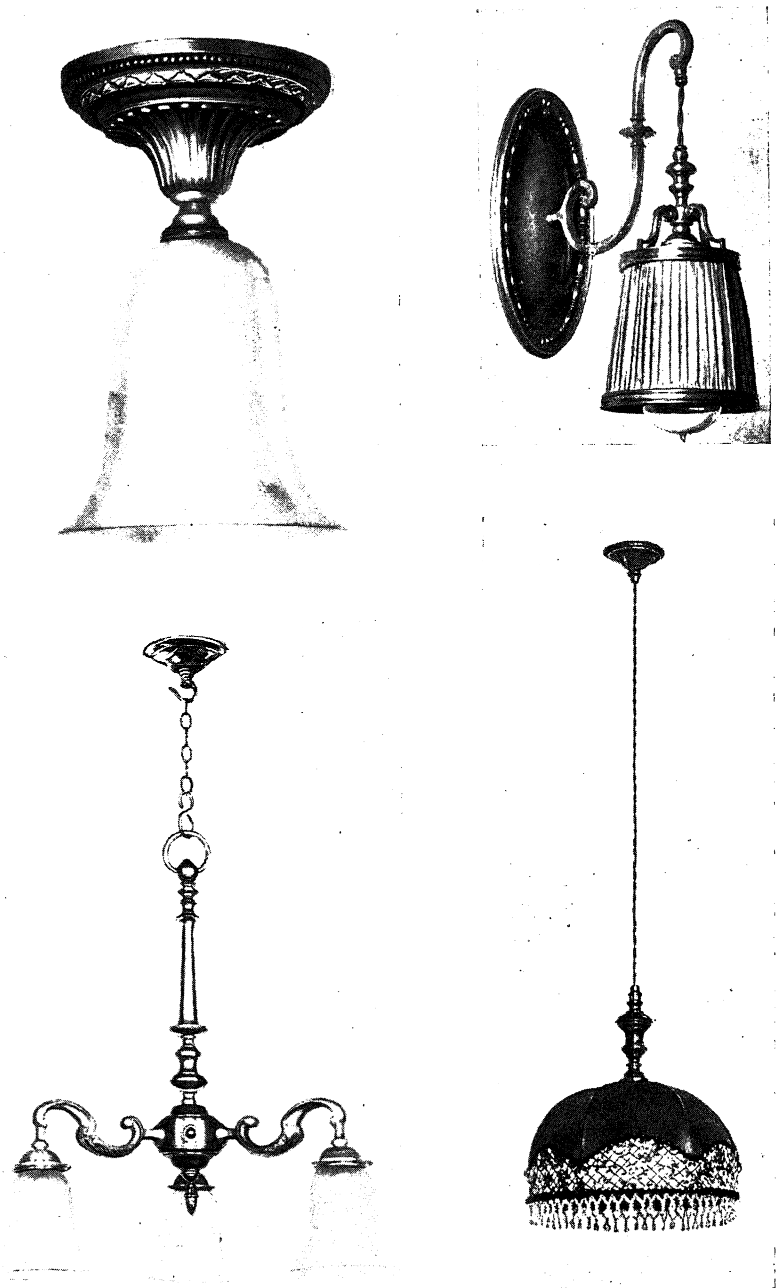
In tungsten lamps as originally manufactured it was found necessary to obtain a very high vacuum in the bulb to avoid blackening.

Although the high vacuum drawn-wire tungsten lamp is the most widely used of any type of incandescent lamp at present (1920) in domestic illumination, yet in the last year or two a gas-filled tungsten lamp has been introduced, having a still higher luminous efficiency.

In this lamp the glass bulb is not exhausted, but is filled at a reduced pressure with nitrogen, argon, or some inert gas, and its presence reduces the tendency of the tungsten to volatilise, and therefore it can be worked at a higher temperature. To reduce the effect of convection in cooling the filament the latter is wound in a set of close spirals with short straight pieces between. A tubular neck on the top of the bulb forms a cooling chamber for the heated gas. The luminous efficiency varies from 1·8 to 2·0 c.p. per watt, with a useful life of about 1,000 hours (see Plate 6, page 163).

Owing to the concentration of the filament in a small space the intrinsic

PLATE 7.



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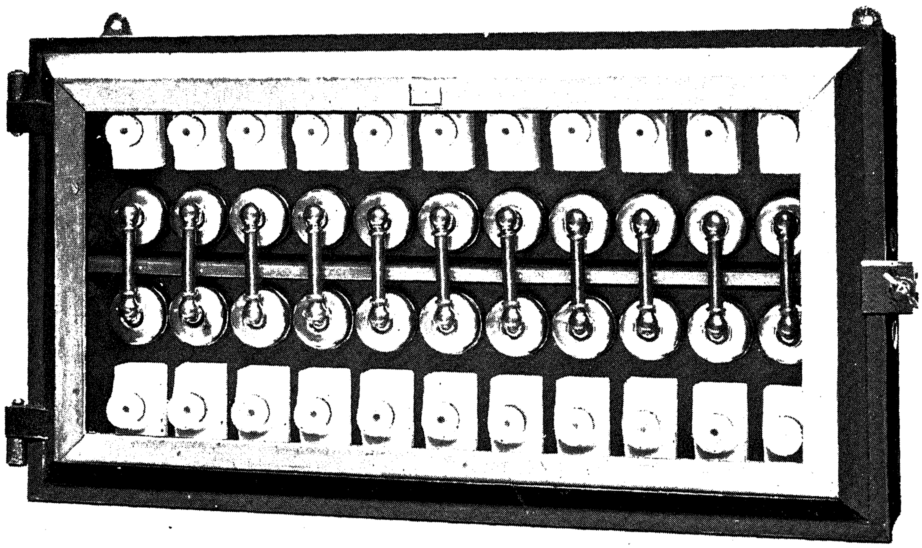
Modern Electric Light Fittings. (See page 168.)

[*To face page* 166.

PLATE 8.



[By permission of Messrs. the English Electric and Siemens Supplies, Ltd.

A Distribution Board fitted with Siemens Zed Fuses. In the centre are the double-pole switches controlling the current to each branch circuit, and at the top and bottom the porcelain plugs containing the circuit fuses.

[To face page 167.

brilliancy of the filament is greatly increased and it is painful to most eyes to look directly at it.

These gas-filled lamps are called "half-watt lamps," because they emit one candle-power of light for every half-watt of electrical power expended in them. They are now made in very large sizes (2,000 c.p. or more) for street and open space illumination. When used for interior lighting (except shops) some form of shade or reflector must be used to prevent the eye from being injured by a direct view of the intensely brilliant filament. The half-watt lamp is more costly than the vacuum lamp, but its greater first cost is recovered in the diminished cost of electric energy by its greater efficiency after a certain number of hours' use. It has become a very formidable rival to both flame arc lamps and high pressure gas lamps in street lighting.

Attention must next be directed to improvements in the employment of incandescent electric lamps. In the early days the chief idea seems to have been to adapt them for use on ordinary gas fittings. Hence they were attached to brackets or fixed on chandeliers. A much used method on account of its low cost was to employ a pendant lamp. The current was led to the lamp by a pair of flexible copper conductors, each made of fine wires twisted together and insulated with india-rubber, the two being held together by a plaited envelope of silk or cotton.

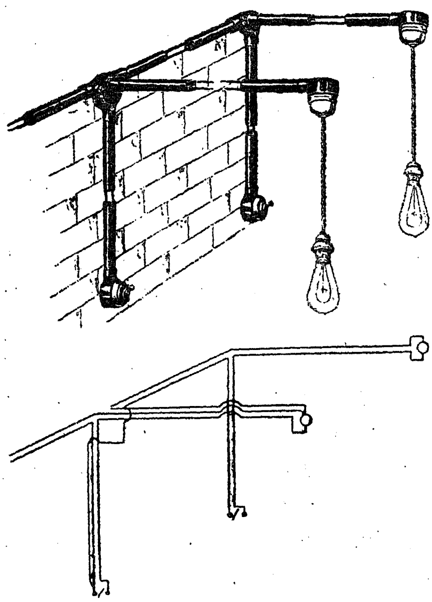
The Edison screw socket and lamp collar still remains in use in the United States and elsewhere, but in Great Britain and on the Continent the usual practice is to equip the lamp with a brass collar and two semicircular brass sole plates, which form the terminals of the filament and are fixed on the base and held in position by some insulating cement or enamel. The corresponding lamp socket has a brass collar with bayonet-slots in its shell, and these hold in the lamp by means of two pins fixed in the sides of the lamp collar. A couple of insulated pins in the interior of the socket then press against the bottom contacts of the lamp when the latter is inserted into the socket.

A very common mode of attachment is then to fix a length of flexible cord to a ceiling rose by means of which the conductors are brought into connection with the supply mains, and to fix at the lower end a lamp socket having over it a shade or flower-shaped glass bell. The lamp is

put on or off by looping down the supply main to a switch (see Plate 7, page 166).

In bedrooms this pendant lamp is made to raise or lower by passing the flexible cord over a couple of porcelain pulleys with a balance weight attached to one of them.

For living-rooms more ornamental fixtures and electroliers are used. The two principal systems of internal electric wiring which have been developed and used are the casing and conduit systems.



[*Courtesy of Messrs. Simplex Conduits, Ltd.*

FIG. 6.—Steel Tube Conduit System of Electric House Wiring, showing the mode of looping back the wire from the ceiling rose to the wall switch.

In the casing system grooved wood slips having a wood cover are nailed to the walls and under the floor boards; and in them india-rubber covered copper wires are placed and retained in position by screwing on the casing cover. In old days it was the custom to run one or more electric mains up a building and to branch off from these wires of lesser section to various rooms. At the junctions of main and branch leads junction boxes were placed which contained a porcelain plate carrying a lead wire called a fuse. If, then, any cross connection caused a rush of current into a branch, the fuse wire melted and cut out the damaged section. This mode of electric wiring, called the *tree-system*, resulted in the fuses being placed in awkward and often dangerous places, and the wood casing system, unless carefully put in in dry places, led to leakage of current and to electric fires in damp places.

The system now always used in good practice is the steel conduit system, and the wires are looped in without any jointing, and each separate branch line is brought back to a distribution board, sub- or main, on which

all the fuses are placed. A main distributor board is always placed in a convenient position on which are fixed the main fuses and control switches for each section of the wiring, and to which the main leads from the external supply cables are brought (see Plate 8 and Fig. 6).

In the conduit system solid drawn seamless steel tube is used, into which the pair of india-rubber insulated wires are drawn. These tubes screw into each other by means of steel sleeves, and it is essential the interior of the tubes should be perfectly free from any sharp edges and well lacquered to prevent rust. At each point where a change of direction takes place a small iron box, called a drawing-in box, is placed. The tubes can be placed under floor-boards or set in the walls and covered in with plaster provided easy access is obtainable to the drawing-in or junction boxes. Each tube runs back to a distribution board generally placed outside the door of the room supplied, and on this board are placed the fuses. The type of fuse now preferred is called a cartridge fuse. In a porcelain tube is stretched a fine wire of copper or tin, and the tube is packed full of powdered kaolin or chalk or some incombustible non-conducting powder. The wire terminates in metal blocks or collars at the ends by which good contact is made with spring clips when the fuse tube is in place in its holder. If the current exceeds a certain safe value the fuse wire melts, but the powder prevents the scattering of metallic vapour or the starting of an electric arc, which might be the cause of other damage (see Plates 8 and 9). The use of higher electric supply voltages necessitates the use in all cases of "quick break" switches. In these, the metallic contacts which close or open the electric circuit must make good hard contact between clean metal surfaces when closed, and when the handle (which should be insulated) is moved to open the switch, the contacts should spring quickly away and leave a long gap in the electric circuit.

In the use of the high-efficiency tungsten lamps, owing to the intense brilliancy of the filament, different arrangements are required. One pleasing method is to suspend from the ceiling by ornamental chains a porcelain or semi-opaque glass bowl. In the interior of this, one or more half-watt lamps are placed, and fed with current by flexible conductors running down the chains. The bowls are fixed so high up that persons sitting or standing on the floor cannot see the lamps themselves, but all the

light that reaches them is diffused through the bowl or else reflected downwards from the white ceiling (see Plate 5, page 162).

In other cases the lamps are placed on a cornice running round the room, and a protecting shield, which is painted white on the side next the lamps, reflects the light up to the ceiling or wall above, so that only diffused light reaches the eyes, and no actual lamp is visible. A very good example of this mode of illuminating a large room is seen in the public meeting room of the Institution of Civil Engineers, Great George Street, London.

Of late years great attention has been paid to the subject of Illumination as a Science and Art, and the *Society of Illuminating Engineers* was started in 1907–8 by Mr. Leon Gaster, the aim of which was to collect and diffuse knowledge on the subject.

As the basis of this branch of engineering is necessarily the measurement of light and illumination, a few words must be said on the subject of Photometry or the Measurement of Light.

The two fundamental measurements necessary are—

(1) The intensity of a source of light, and

(2) The brightness or illumination of a surface on which that light falls.

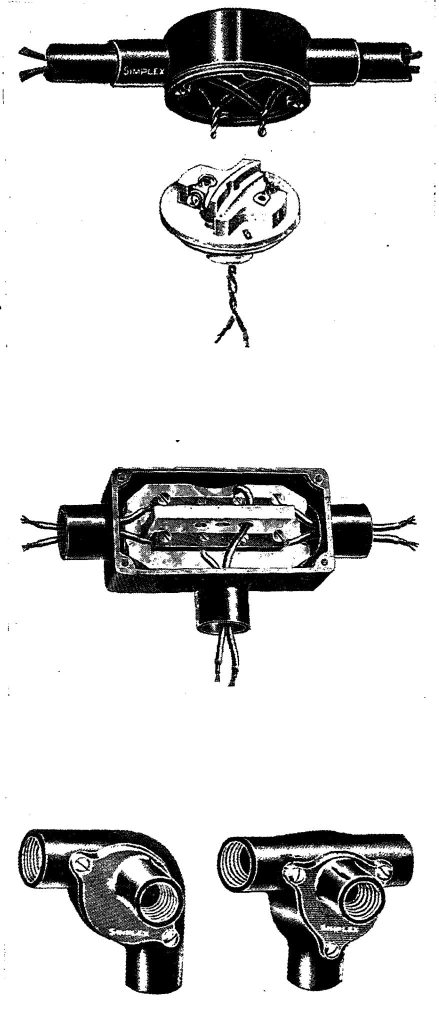
Apart from tactile, muscular, and aural sensations we obtain our knowledge of the external world chiefly by visual impressions. These when divested of the inferences which come from other remembered or associated sensations, resolve themselves into an appreciation in the field of view of patches or areas which differ (1) in colour; (2) in form or outline; and (3) in brightness.

Although the colour differences add much to our pleasure, the two last, viz., form and brightness, or shape and relative light and shade, as we say, are the most important.

A photograph, for instance, presents us with a perfectly recognisable reproduction of certain things in nature, but divested of all colour differences. It requires some experience to decide when two surfaces have the same degree of brightness or illumination apart from colour differences.

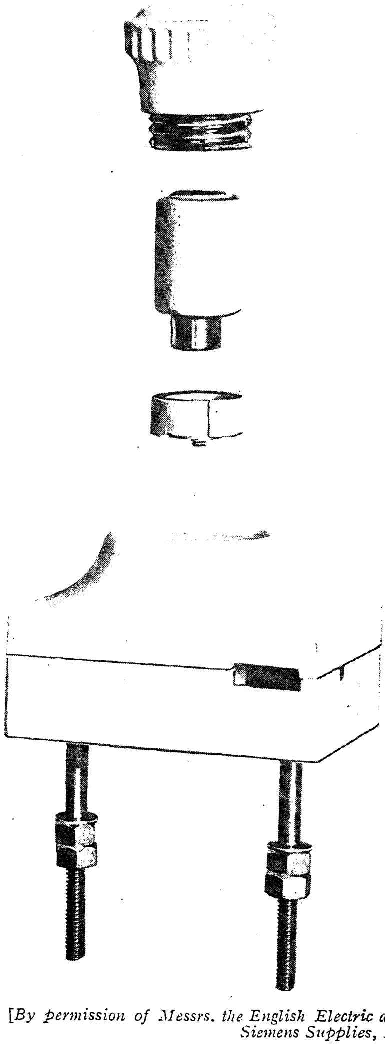
Confining ourselves to white surfaces, viz., those which perfectly reflect without selection all rays of light falling on them, we can compare two such surfaces with regard to their illumination.

PLATE 9.



By permission of Messrs. Simplex Conduits, Ltd.

Details of Drawn Steel Conduit Tube for Running Electric Light Wires.

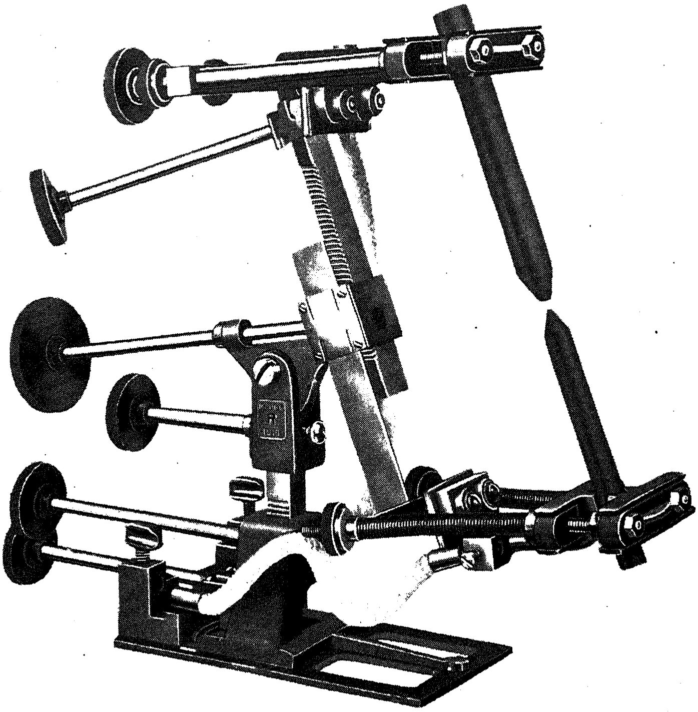


[By permission of Messrs. the English Electric and Siemens Supplies, Ltd.

Details of a Siemens Zed Fuse. The fuse wire is contained in the cartridge which is the second object from the top in the illustration.

[*To face page* 170.

PLATE 10.



[By permission of The Gaumont Co.

A Hand-regulated Electric Arc Lamp as used in Optical Lanterns for Projection.
(See page 178.)

[By permission of Messrs. the Edison and Swan Co.

An Ediswan Point-o-lite Lamp.
(See page 178.)

[To face page 171.

The unit of illumination is that produced by a source of light of unit intensity at a unit of distance from a white surface.

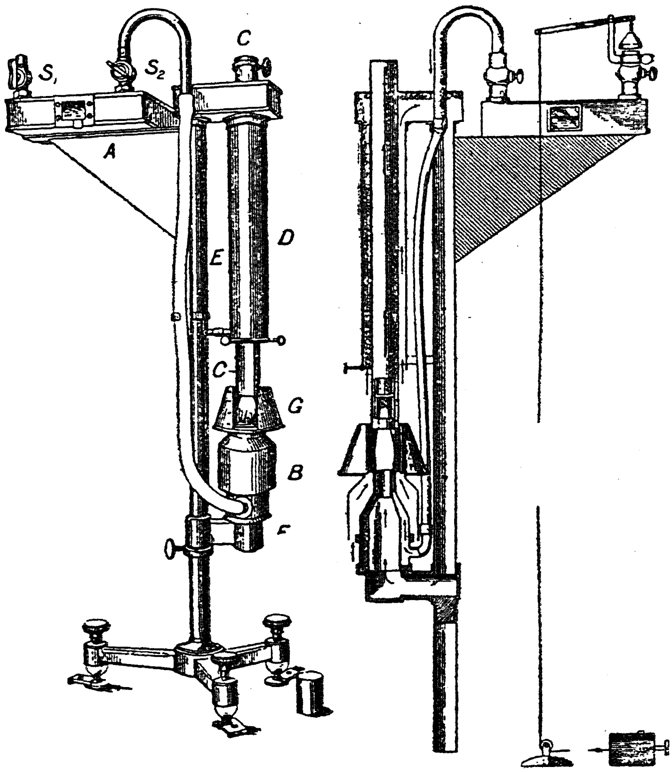


FIG. 7.—The Vernon Harcourt Pentane Standard Lamp. B. The burner. D. The chimney. S_1. The pentane reservoir. The pentane vapour, being heavier than air, is syphoned down a tube to the burner. G is the flame, a definite length of this flame being exposed to radiate a constant amount of light.

Various units for the comparison of intensity of light sources have been used.

In Great Britain it is taken to be the standard candle or else the international candle.

When gas lighting was first controlled by the Legislature in 1860, it became necessary to fix a standard of light. This was defined to be that

of a candle made of spermaceti tempered with beeswax, weighing six to the pound, and burning at the rate of 120 grains of spermaceti per hour.

The candle so defined is, however, a not very accurate or constant unit of light, even when the instructions for employing it are strictly followed.

Hence, later on, a standard lamp, due to the late Professor A. G. Vernon Harcourt, was introduced, called a Pentane standard. It is a form of wickless lamp burning the vapour of a combustible volatile liquid called pentane (C_5H_{12}), and when used as prescribed, gives a light equal to the mean of ten standard candles (see Fig. 7).

Various other standards have been employed, such as the International Candle, or Bougié décimale, agreed upon as a universal standard.

A Hefner unit of light, defined by a lamp burning a liquid called amyl acetate in a lamp of certain form with flame of defined height, is used in Germany, and another French standard exists called the Carcel lamp, a certain kind of oil lamp.

Taking the International Candle as the reference unit, the British or Parliamentary Candle is 1·02 units, the Hefner is 0·9 unit, and the Carcel is 9·6 units.

All flame standards of light are, however, variable with atmospheric pressure or height of barometer, and with moisture or hygrometric state of the air.

The important matter is that the standard shall invariably reproduce the same amount of light.

Some years ago the author devoted much attention to the subject of light standards and, after many experiments, was able to show that incandescent electric lamps made in a certain way could provide a very constant source of light to be used as a standard.

It has been pointed out that incandescent lamps, whether carbon filaments or metallic filaments, become more or less blackened on the interior of the bulb by a deposit of carbon or metal derived from the filament, with use. This diminishes the light emitted by it as time proceeds, and the lamp is said to "*age*."

The question then arises whether this diminution in light is merely due to the obscuring of the bulb or to any change in the filament itself. This was tested by removing the filament from an aged lamp and putting

it into a new clear bulb. It was found that when the filament had been used for some time it thereafter reproduced the same light for the same current passing through it provided the bulb was kept clear or unblackened.

This, then, suggested a method for making a non-ageing lamp. A filament of carbon was mounted in a bulb and rendered incandescent by a current for some time, say 100 or 200 hours.

The filament is then remounted in a very large clean glass bulb, which is exhausted carefully. This large-bulb incandescent lamp will then preserve an extremely constant standard of light if it is used occasionally for comparison and always in use has the same electric current passed through it adjusted to such a value as not to exceed, for a carbon lamp, a power consumption of about 3·5 watts per candle (see Fig. 8).

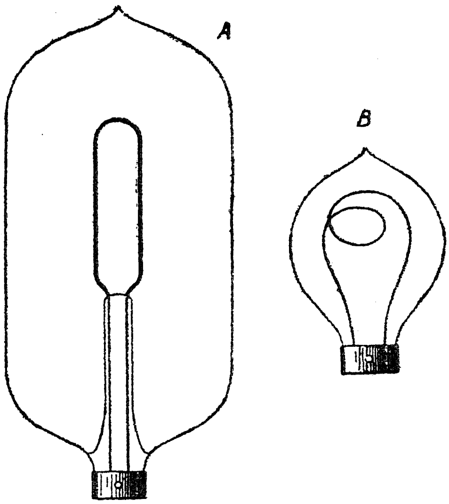


FIG. 8.—A. Fleming Large-bulb Standard Incandescent Lamp. B. An ordinary carbon filament 16-c.p. lamp for comparison of size with the large-bulb lamp.

Many large-bulb standard lamps of this type were made for the author by the Edison Swan Company, called Fleming Large-bulb Standard Lamps, and when used as described were found to preserve a constant unit of light over long periods of time, and to be extremely convenient for determining the variation of different flame standards.*

Having defined our standard source of light, say the International Candle, we define our unit of illumination or brightness by stating that it is the illumination produced by one standard candle illuminating a white surface, placed at a distance of one unit, say 1 foot. This is called a

* These standard lamps were fully described in a paper read by the author to the Institution of Electrical Engineers in 1902 (see *Journ. Inst. Elec. Eng. Lond.*, vol. 32, 1903). This paper was awarded the Institution Premium for that year. These large-bulb photometric lamps have been in use in the Pender Electrical Laboratory of University College, London, since 1896, when they were first made by the author, and their constancy fully confirmed by many researches.

candle-foot illumination, or, if we use metric units, we might take the Bougie-metre or Carcel-metre as a similar unit. The candle-foot is, however, very convenient, because it happens to be the minimum illumination on a sheet of white paper which enables us to read print or writing with any comfort.

The illumination at different distances from a source varies inversely as the square of the distance, and directly as the intensity of the source. Thus at 2 feet from a standard candle the illumination is only one quarter of a candle-foot, and a source of 9 c.p. illuminates a surface at a distance of 3 feet with an illumination of one candle-foot. The total amount of light falling on a surface is measured in *lumens*. The lumen is the amount

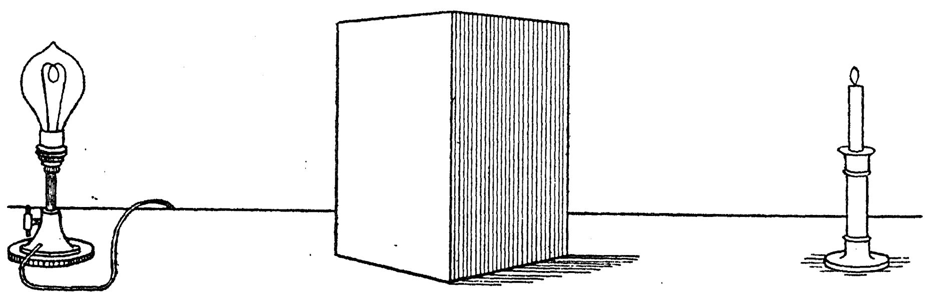


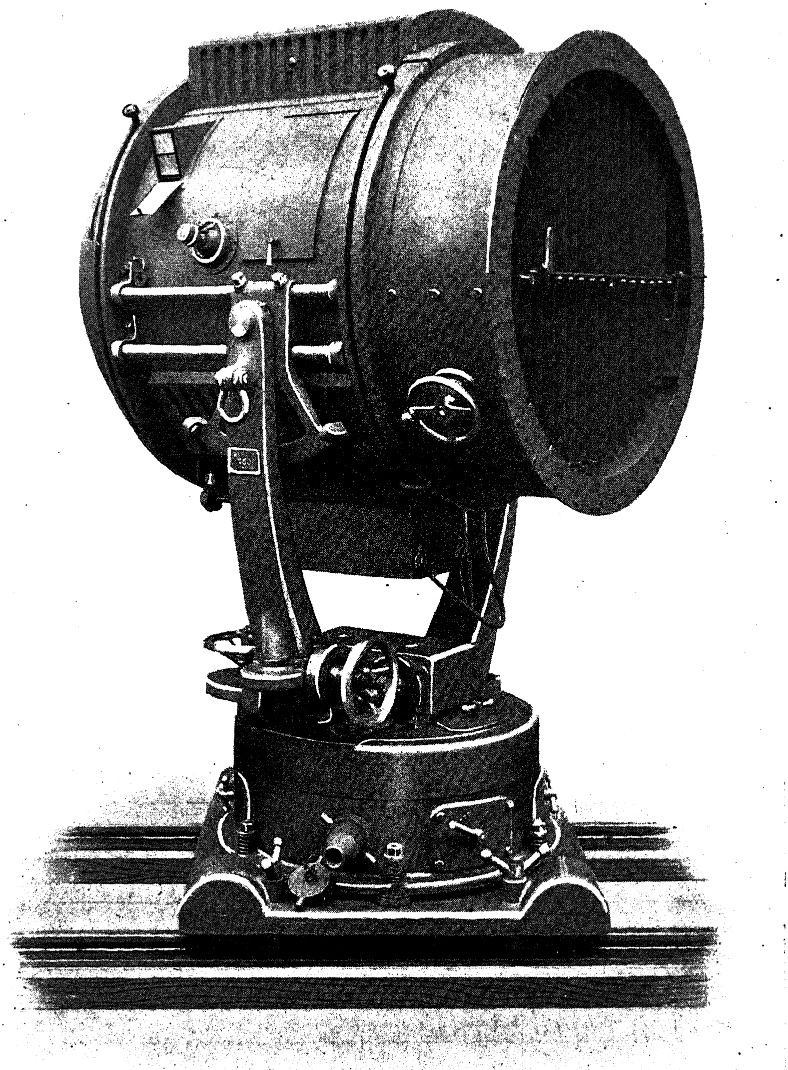
FIG. 9.—Method of comparing the relative Illuminating Powers of an Incandescent Lamp and a Standard Candle by means of a white wedge Photometer.

required to illuminate 1 square foot with a brightness of one candle-foot. Since the total solid angle round a point is 4π units, the total emission from a source of light in lumens is $88/7$ ($= 4\pi$) multiplied by the candle-power of the source. A scientific measure of the luminous efficiency of a source of light is the lumens emitted per watt of power expended in it.

To compare sources of light as regards candle-power or intensity we have, therefore, to illuminate respectively two identical white surfaces and adjust the distances of the sources until the illumination of these sources is judged by the eye of an observer to be equal.

To do this accurately requires that the boundary line between the two surfaces shall be very sharply defined, and the surfaces closely adjacent. A simple means of effecting this is by a wedge photometer (see Fig. 9). A prism or wedge has its surfaces painted dead white and its edge made

PLATE 11.

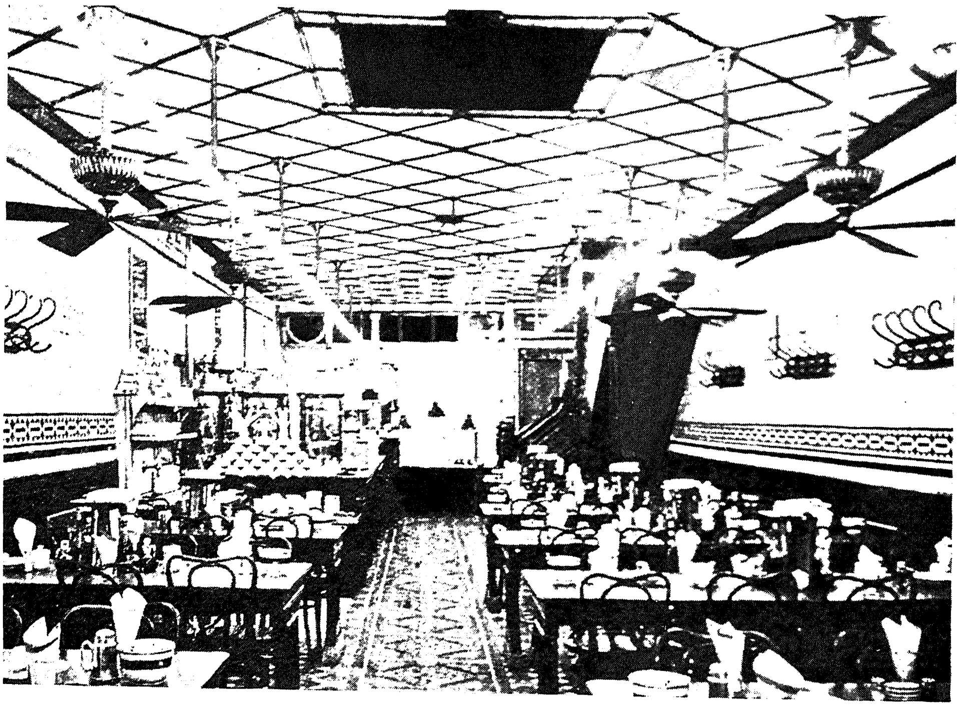


[*By permission of Messrs. Siemens Bros.*

An Electric Arc Search Lamp. The cylinder has a parabolic mirror at the back and a self-regulating arc lamp in its focus.

[*To face page* 174.

PLATE 12.



A View of a Restaurant Illuminated by Moore Vacuum Tube Lamps fixed to the ceilings giving a very pleasant diffused light.

[To face page 175.

very sharp. If held between two sources of light with the edge vertical and two inclined surfaces making equal angles with the line joining the sources of light, these are illuminated each by a single source. We then move the wedge to or from one source until the illumination of the two sides is judged to be equal. The relative intensity of the sources is then

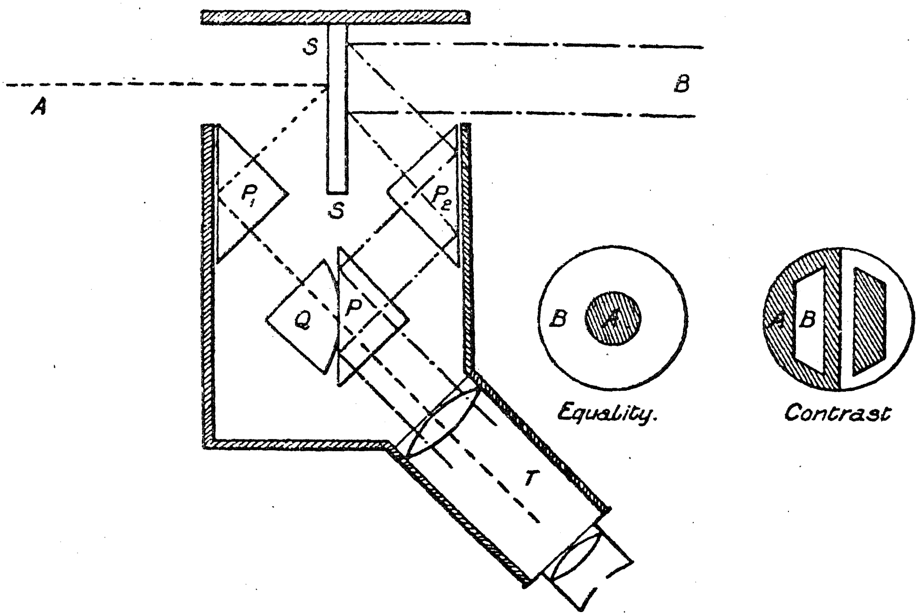


FIG. 10.—A Section on a Horizontal Plane of a Lummer-Brodhun Photometer. In a brass box are placed four glass prisms P_1, P_2, P and Q, and these are viewed through a telescope T. A dead white screen S is illuminated on its two sides by two sources of light A and B. The rays from A pass along the dotted line, and those from B along the broken line. The prism Q has a curved surface ground flat at one place, and the result is that in the field of view is seen a circular area formed with light from A, surrounded by a field of light from B. The distance of the two lights is varied until these areas become equally bright.

directly as the square of their distance from the wedge. Thus, if the wedge is 2 feet from one source and 5 feet from the other when this equality is established, the intensity of the light source at 5 feet is to that at 2 feet as twenty-five is to four.

All forms of instruments, called photometers, for making such comparisons depend on the above principle, but they differ in the manner in which these two illuminated areas are brought into comparison. One

of the best, called a Lummer-Brodhun photometer, achieves it by the use of a certain form of glass prism by which the diffused light on two opposite sides of a white screen illuminated by the two sources of light is made to produce two sharply defined adjacent areas in the field of view of a telescope (see Fig. 10).

In making a photometric measurement of any source of light it is essential to state the direction in which that light is emitted. Suppose it to be an incandescent lamp placed with axis vertical and the measurements to be made in a horizontal direction. Owing to the want of symmetry in the form of the filament, the intensity in various horizontal directions may be different. We can take the mean of various measurements in different azimuths or we may make the lamp revolve seven or eight times a second round its vertical axis. The resulting photometric comparison with a standard candle or lamp will give us the *mean horizontal candle-power* (M.H.C.P.).

But the light in other directions will have different intensities. By certain methods we can take the mean of a very large number of measurements in directions at all azimuths and elevations. The result will be to give us the *mean spherical candle-power* (M.S.C.P.) or mean hemispherical if we take half the sphere.

We may define the M.S.C.P. to be the candle-power of a source of light which emits equally in all directions a total quantity of light in lumens equal to that emitted by the source considered. This M.S.C.P. or M.H.S.C.P. is important in the case of arc lamps in which the intensity of the light emitted is very different in different directions.

In the illumination of private dwellings or public rooms or streets the important matter is the illumination (reckoned in candle-feet) either on the table or walls or street surface.

In general the illumination must be at least 1 candle-foot (c.f.) on any surface, table, book, paper, etc., to enable us to read or see with comfort. For billiard or dining tables or drawing offices, or work benches 1 to 5 candle-feet are necessary, and on theatres, stages, or in shop windows, anything up to 10 candle-feet may be requisite.

In most private rooms it is not necessary to illuminate the walls or ceiling so highly as the tables and floors, and the light is sent downwards

by shades or reflectors. A great deal depends, however, on the nature of the wall colour, and on whether there are pictures to be seen. Every one has noticed the general improvement that takes place in the illumination of a dining room when the white tablecloth replaces the usual dark cloth on the table, or the effect produced in a bedroom by replacing a dark-coloured paper or wall distemper by a very light one.

Hence it is difficult to lay down absolute rules for the number of lamps or total candle-power required for a room of given floor area or cubic space.

Broadly speaking, we have generally to provide one mean spherical candle-power for each 2 square feet of floor area, or 30 cubic feet of space in the form of lamps placed about 7—10 feet above the floor to give a comfortable illumination.

Thus a room 20 feet by 16 feet in area would require 160 M.S.C.P., or say, five 32 c.p. lamps placed 7—10 feet above the floor.

As regards street lighting, or that of open spaces, the most economical form of lighting is probably the tungsten half-watt lamp. Careful tests made at Manchester by the corporation established that flame arc lighting was cheaper than high pressure gas lighting for equal illumination, and gave a better distribution of light. Nevertheless, the trouble of recarboning and loss of light by the obscuration of the glass globes diminishes greatly its all round utility.

The illumination required on the street surface will necessarily vary with the nature of the street, and it cannot in any case be very uniform.

It may vary in a ratio of 4 or 6 to 1 between maximum and minimum or it may even be 40 or 50 to 1. The minimum value should not be less than 0·1 or 0·2 c.f.

With ordinary open type of arcs placed 25 or 30 feet above ground this will be secured by placing the lamps about 80 to 100 feet apart, and flame arcs a little farther and higher.

The half-watt tungsten lamp, requiring no labour for re-carboning, is becoming a strong competitor for street lighting, and can hold its own with every form of illuminant except perhaps the flame arc lamp.

Moreover, they can be run off the house supply circuits, and require no special cables and dynamos as in the case of arc lighting.

We may notice in conclusion certain special forms of electric lamp having technical uses.

In the case of optical lanterns, so largely used in scientific lectures and in picture palaces for working the kinema projectors, the usual and best illuminant is the hand-regulated focussing arc lamp.

In this lamp the two carbons are held in an inclined position, the positive or crater carbon being placed just a little out of line with the other, so that the light from the crater may be sent out towards the condensing lens of the lantern. The carbons are moved by rackwork and pinions, so that a single rotation of a wheel brings them towards, or moves them from, each other whilst keeping the crater at the same level. There are other adjusting screws for raising the two carbons both at the same time or moving them to right or left, as required, to bring the crater exactly into the focus of the lens. The operator starts the arc by bringing the two carbons together and then separating them slightly, and a slight rotation is given to the adjusting screw from time to time as the carbons burn away (see Plate 10, page 171). The hand-regulated arc is found better for this purpose than any self-regulating arc.

Owing to the great heat given out by large arcs, it is necessary to have a water-cell, viz., a box, with parallel sides of glass plate, filled with water to intercept the heat rays, which would otherwise set the film on fire.

Another form of optical lamp is the Point-o-lite Lamp of the Edison and Swan Electric Light Company.

In this lamp there is a thick straight wire of tungsten supported in a vacuum bulb. This can be rendered incandescent by sending a current through it. Near to the wire, but not touching it, is a tungsten ball carried on a third terminal. If the ball is connected to one side (the positive) of a supply circuit, and if the incandescent tungsten wire is connected to the other side, an electric arc will start between the wire and the ball, which will be maintained even if the current which renders the wire incandescent is cut off. The arc starts spontaneously, because making the wire incandescent causes it to emit electrons (see Chapter VI.), and also ionises the residual gas near it. The result is that an intensely brilliant short electric arc is maintained between the wire and the ball

and is very suitable for optical work because its small size enables it to be placed exactly in the focus of a lens or mirror (see Plate 10, page 171).

The author also invented many years ago a form of incandescent lamp called a focus lamp, in which a carbon or metallic filament is coiled into a small flat spiral or zigzag, so as to concentrate the light given out by it in the focus of a lantern lens or mirror (see Fig. 11).

Another special application of electric arcs is in searchlights.

An electric arc is placed in the focus of a large parabolic mirror made of polished metal. The result is to project a parallel beam of intense light. The mirror and included arc lamp are fixed on a stand, so that it can easily be moved to project the beam in any required direction. The carbons are generally set in a horizontal direction with the crater of the positive carbon exactly in the focus of the parabolic mirror. The arc lamps used are mostly self-regulated by means of a shunt and series coil, and employ very thick carbons.

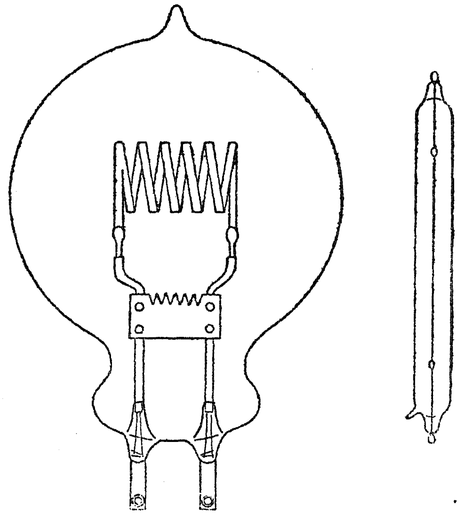


FIG. 11.—A Focus Incandescent Lamp with filament in the form of a flat spiral for use in optical lanterns.

The ordinary sizes take 30—35 amperes, but larger projectors up to 200 amperes. The best mirrors are gilded on the surface, as the rays from a gilt mirror penetrate fog better (see Plate 11, page 174).

Such projectors were originally designed for use in guiding ships at night in passing through the Suez Canal or into harbour. They were then adopted on battleships as a means for searching for enemy torpedo boats, and found most extensive use during the European War, 1914–1918, in searching for and protecting large cities from attacks by aircraft.

A very improved form of projector arc lamp has been devised by Beck. In this lamp the carbons are thin, 16 millimetres for the positive and 11 millimetres for the negative. Very large currents, up to 150,

are put through them, being delivered close to the tips by roller contacts. To prevent rapid burning away of the carbons a jet of methylated spirit vapour is blown upon them. The result is an intensely brilliant crater of about four times the intrinsic brilliancy of an ordinary open arc, and when placed in the focus of a parabolic mirror, it gives a searchlight

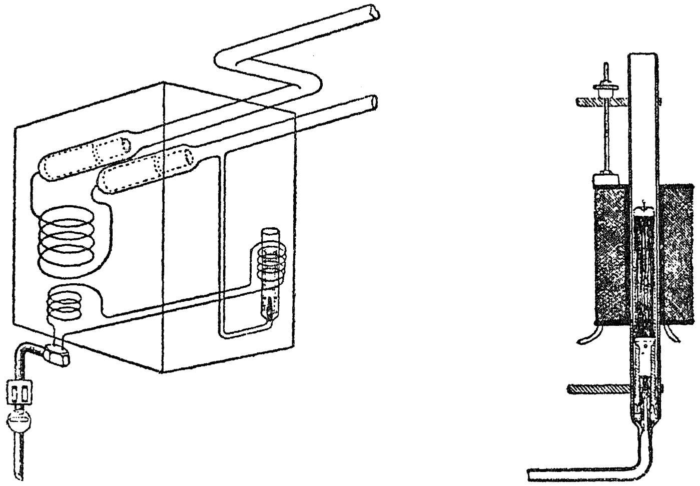


Fig. 12.—Arrangements for Regulating the Vacuum in a Moore Illuminating Vacuum Tube. The electromotive force is supplied to the tube by means of an alternating current transformer, the coils of which are shown as two spirals in the left-hand figure. Any increase of resistance of the tube causes the primary current to act on a valve which admits a little more air or other gas to the tube.

beam of about three times the intensity compared with the ordinary arc-projector of the same mirror area.

A few special types of electric lamp which have limited uses may be mentioned in conclusion.

The mercury vapour arc lamp is the invention of Mr. Cooper Hewitt, and is very efficient, yielding a light of 1 c.p. for 0·6 of a watt, or 1·66 c.p. per watt. It is produced by placing mercury in a highly exhausted glass tube having wire electrodes sealed through the glass tube ends, which project into pools of mercury kept at the tube ends in bent portion of it. The arc is started by tilting the tube so that a stream of mercury unites the two pools for a moment and then separates. The arc is then formed

and kept up by an electric discharge through mercury vapour. The light is of an intense green and highly actinic. Hence it is useful for photography of certain kinds, but as it gives the human complexion a very ghastly appearance it is not suited for general use.

Vacuum tubes containing neon, one of the rare atmospheric gases, have been used as illuminants to some extent. When a high-voltage electric discharge is sent through neon at low pressure contained in a glass tube having platinum electrode wires sealed into the ends, the gas glows with a brilliant rosy light (see Plate 12, page 175). A 20-foot tube can be made to yield a light of 900 c.p., with a power expenditure of about 1·3 watts per c.p. Such vacuum tubes have been used to a limited extent for lighting.

In September, 1907, the author tested and reported upon a system of vacuum tube lighting due to Mr. D. Macfarlane Moore. The rarefied gases used in the tube were either air nitrogen, or carbon dioxide, and were contained, at a pressure of 1 or 2 millimetres, in long glass tubes with platinum electrodes sealed into each end. The high voltage current required to make the gas glow was provided by an alternating current transformer. As the tube is worked the vacuum continually gets higher, due to absorption of the gas. Hence an important element of the invention consisted in a "breathing valve," by means of which a small amount of fresh gas was admitted to the tube from time to time. This was automatically done by the decrease in the electric current which takes place as the vacuum becomes too high (see Fig. 12).

The glass tubes used are about 2 inches in diameter and 10—20 feet long, and the voltage required is about 75 volts per foot run of tube. The light emitted varies with the gas used. Nitrogen gives a rosy-yellow, and has an efficiency of about 0·6 c.p. per watt expended.

The intrinsic brilliancy is low, only 1 to 2 c.p. per square inch, but this renders diffusing globes unnecessary. Lamps up to 200 or 300 feet in length can be used, and they are convenient for certain kinds of shop and outdoor lighting. The only risk attending them is the high voltage required at the terminals.

A full description of the Moore light and its mode of use was given by the author in an article published in *The Illuminating Engineer* for 1908, Vol. I., p. 19, entitled "Vacuum Tube Lighting."

We are, then, led to consider a very important matter, viz., the possible improvements in the efficiency of sources of illumination.

In the carbon filament lamp, out of all the power given to the filament to heat it, only about 3 per cent. or less is used in creating radiation which can affect the eye as light. In the arc lamp, owing to the much higher temperature of the carbons this luminous efficiency is from 10 per cent. to 12 per cent. In the vacuum tungsten lamp it does not probably exceed 7·5 per cent., whilst in the half-watt gas-filled lamp the efficiency approximates to that of the open arc lamp. The flame arc lamp has an efficiency three to five times that of the ordinary open carbon arc.

The proportion which the radiated luminous energy bears to the total radiated energy depends upon the temperature of the source of light, at least, in those cases in which the light-emitting power of the source is due to high temperature. Thus, if we heat a carbon filament *in vacuo* it first radiates non-luminous rays or dark heat. As the temperature rises luminous rays of gradually decreasing wavelength make their appearance, whilst the energy of all other wavelengths increases. The energy radiated in the form of light is, however, always small compared with that of the dark heat rays which cannot affect the eye.

Even in the case of the sun, which at least in the outer layers has a temperature of 6,000° C., the proportion of luminous to total radiation does not much exceed 30 per cent. Hence it will be seen that all our artificial sources of light in this sense are very inefficient. But it has been shown that certain natural sources of light, such as that of the fire-fly and glow-worm, vastly exceed in efficiency anything the human mind has been able to devise. The researches of Langley and Very have proved that these insects, and probably also the organisms to which the phosphorescence of the sea is due, possess the secret of being able to manufacture light without heat. Experiment has shown that the luminous efficiency of the fire-fly is about 95 to 97 per cent.

The production of light in these cases does not depend solely on temperature, but on chemical or vital processes. The modes of light production which do not depend upon a high temperature have been called *luminescence* to distinguish them from the modes which do depend on heat, which might be called *calorescence*. It is clear, therefore,

that there is an almost boundless field for research in the discovery of more economical means of producing light than we now possess. With the ordinary tungsten lamp we can produce at present a light equal to 500 c.p. by the expenditure of 1 h.p. With the half-watt tungsten lamp we can produce nearly 1,500 c.p. with 1 h.p. If, however, we can penetrate into the fire-fly's secret we may be able to produce 5,000 or, may be, 10,000 c.p. with 1 h.p.

Every electric lamp is merely a device for transforming the energy of an electric current in part into the energy of waves in the æther of which the wavelength lies between $\frac{1}{70000}$ and $\frac{1}{40000}$ part of an inch.

The efficiency of the dynamo and electric motor as energy transformers approximates to 80—95 per cent., and in these energy-transforming devices there is, therefore, but little room for improvement in that sense, but in electric lamps, on the other hand, there is a vast field open for research in the endeavour to discover practical sources of artificial illumination which will bring the lamps more on a level as regards efficiency of transformation with the other appliances just named.

CHAPTER IV

ELECTRIC HEATING, COOKING AND FURNACES AS DEVELOPED IN FIVE DECADES

AT a very early stage in the study of the powers of electric currents, as generated by voltaic cells, it was noticed that a current of electricity heats a conductor, say, a wire, through which it passes. In fact, this is one of the tests for the presence of an electric current.

The production of this heat is dependent upon a certain quality in the conductor, called its electric resistance. This resistance is a measurable quantity (see Chapter VI.), and is reckoned in units called an ohm.

J. P. Joule, an eminent British scientific investigator, showed in 1841 that the heat produced in a conductor of any form is proportional to the product of the resistance of the conductor to the square of the current strength, that is, the numerical value of the current multiplied by itself, and also to the time during which the current acts (Plate I). Electric currents are measurable agencies, and in Chapter VI. some account is given of how they can be measured. Meanwhile it is sufficient to state that the practical unit of current is one called an ampere, and currents are measured in amperes just as distances are measured in feet or miles, or weights in tons or pounds.

It is essential at the outset that the reader should clearly understand the difference between *quantity of heat* and *temperature.*

Heat is a form of energy, viz., the energy of motion of atoms or electrons which are constituents of atoms.

Hence, quantity of heat is identical with quantity of energy and can be measured in the same units.

We have to expend energy when any displacement of material substances is made against a force which resists it. Thus, if we lift up a mass of 1 lb. against the force of gravity 1 foot high we do 1 foot-lb. of work or expend that amount of energy. Here again it is essential to possess

a clear idea of the difference between *work* or *energy* and *power* or *rate of doing work*. If we lift a mass of 1 lb. 1 foot high against gravity, we do work equal to 1 foot-pound, whether we lift it slowly or quickly. If we lift it in one second, we do 1 foot-pound *per second*, and if we lift it in half a second, we do work at the *rate* of 2 foot-pounds per second. A rate equal to 550 foot-pounds per second is called 1 *horse power*. A rate of doing work equal to about $1\frac{1}{3}$ h.p. is called a *kilowatt* or 1,000 watts, and the quantity of work done when this last power operates for an hour is called *one kilowatt-hour*, or one Board of Trade unit of energy. Quantity of heat or heat energy may, therefore, be measured in *foot-pounds* or in metrical units, such as the *kilowatt-hours* or Board of Trade units in which we measure electric energy.

On the other hand, temperature is a measurable quality analogous to voltage in electricity or difference of level in hydraulics. It is that which determines the direction in which heat flows. Heat moves in conductors from places of high temperature to places of low temperature, and never in the opposite direction, just as water flows down hill and never up hill, or from high levels to low levels. If we pump water up to a higher level we have to exert energy or do work, and the work done is measured by the product of the weight of water lifted and the height in feet through which it is lifted. In the same manner quantity of heat may be measured by the energy required to raise a standard mass, viz., 1 lb. of water through a certain range of temperature. Two fixed temperatures are (1) the melting point of pure ice, and (2) the boiling point of pure water when the barometer stands at 760 millimetres height, viz., about 30 inches.

Since, in general, substances expand or increase in volume when heated we can construct a practical scale of temperature as follows :—

We place some mercury in a graduated glass tube, called a thermometer, and observe its volume at the melting point of ice; we then heat it to the boiling point of water at 760 millimetres pressure and observe its apparent volume again. We say that $\frac{1}{100}$th part of this apparent increase in volume is due to an increase in temperature of one degree Centigrade (1° C.), and the whole interval of temperature between melting and boiling point, defined as above, is called 100 degrees.

Careful observations, begun in 1843 by Mr. Joule, have shown that when 1 lb. of water is raised in temperature 1° C., the energy expended in so doing is 1,399·5 foot-pounds.

Heat energy may therefore be measured in two ways: (1) by the product of a distance and a force, as in foot-pounds; or (2) by the product of mass of some standard substance, say 1 lb. of water, and its rise in temperature, say in degrees Centigrade.

If we employ the metric units with the centimetre ($= \frac{1}{100}$ of a metre) as unit of length, the gram as unit of mass, and second as unit of time, then we have the following metric relations. The Board of Trade unit of energy or work, equal to 1 kilowatt-hour, is the equivalent of 3,600,000 watts per second, but a power of 1 watt exerted for 1 second is called a Joule, after the British scientist above named.

It has been demonstrated by repeated experiments that the heat energy required to heat 1 gram of water 1° C. at or about the melting point of ice which is called 1 calorie is nearly 4·2 joules.

Hence it follows that 1 Board of Trade unit of energy is equal to 857,143 calories, or would heat 8571·43 grams or 8·57143 kilograms of water 100° C. Translated into British units this means that 1 Board of Trade unit of energy would suffice to heat about 2 gallons of water from the temperature of melting point of ice to that of the boiling point of water.

Returning, then, to the case of a metallic wire heated by an electric current, we have stated above that this depends upon the resistance of the wire. In the case of a wire of uniform cross-section the resistance is proportional to the length of the wire inversely as the cross-section, and also proportional to a number called the *specific resistance* of the wire, which has a particular value for each substance. The specific resistance of iron, for instance, is about seven or eight times that of copper.

When the current flows through the wire and generates heat in it, this heat escapes in three ways : (1) Part of it is conducted away by the supports which hold the ends of the wire; (2) part of it heats the air and is removed by convection, as it is called; and (3) a third part is radiated as dark or luminous radiation.

These three losses increase rapidly as the temperature of the wire rises.

The wire attains a constant temperature when the rate at which it is losing heat just balances the rate at which heat is generated in it.

We might compare it to a cistern with the waste pipe open being filled by a tap supplying water. The water would rise in the cistern until the rate at which it runs out by the waste pipe is equal to the rate at which it comes in by the tap.

Suppose, then, that we have two equal wires, say of copper and iron, joined in series and send the same electric current through both, the heat will be generated seven times faster in the iron wire than in the copper wire. It escapes from both at about the same rate and hence the final steady temperature will be much higher for the iron than the copper. The iron may, in fact, become red hot whilst the copper is not visible in a dark room.

We can easily calculate the total amount of heating energy put into a wire when we know the current measured in amperes and the resistance of the wire reckoned in ohms, or else the pressure or potential difference between the ends of the wire in volts and the time the current flows. For the power given to the wire reckoned in watts is equal to the product of the current in amperes and the potential difference of the ends, reckoned in volts, assuming we are using a direct current. But the volt drop is equal to the product of current and resistance. Hence the power supplied is measured by the product of the square of the current and the resistance, and the energy by the product of the power and time.

Thus, for instance, if a wire has a resistance of 5 ohms and we put through it a current of 10 amperes for three minutes twenty seconds, or 200 seconds, we should give to it $10 \times 10 \times 5 \times 200$ ($= 100{,}000$) joules of energy. This would suffice to raise about $5\frac{1}{4}$ gallons of water through 10° C., or nearly half a gallon from the melting point of ice to the boiling point of water.

It is clear, therefore, that when we desire to employ an electric current as a heating agency we have to pass it through some substance which has resistance.

When we do not wish to produce heat we must abolish resistance, and this is the reason that all contacts or junctions in an electric circuit should be kept clean and tightly pressed together because a film of dirt

or oxide creates resistance, and therefore heat. The first kind of electric heating to be noticed, therefore, is called *resistance heating*, because it is due to the presence of resistance in some conductor through which a current is sent.

The current may be passed either through the thing intended to be heated in some cases, or in others through a special heating wire which in turn heats the object by radiation or conduction.

There are not many cases in which the required heat can be produced in a substance by passing a current through it, because in general the resistance of that substance will be too great or too small. The most usual method is to pass the current through a suitable resistance and permit the heat so generated to be radiated on the object to be heated. The substances employed as heater or resistance may be coke or graphite, or some refractory metallic alloy.

Platinum cannot now be used on account of its present high price, and tungsten and other refractory metals are, also, too costly. An alloy now much used, called nichrome, is an alloy of nickel and chromium.

It has the valuable quality that it can be heated for a long time to a bright red heat without being oxidised by the air, whereas iron, for instance, if repeatedly raised to a red heat soon becomes oxidised or rusted away.

There are, however, several very important industries which depend upon the fact that an electric current can create heat in a substance of high resistance through which it flows and as a result bring about certain chemical changes in it not produced at low temperatures.

One instance is that of the manufacture of carborundum, a substance of great hardness and largely used for making grinding wheels and tool sharpeners as a substitute for emery.

Carborundum was first made in 1891 by E. G. Acheson during an attempt to make diamonds artificially. It is a compound of carbon and silicon and chemically called a carbide of silicon (SiC).

If sand, which is nearly pure silica, or oxide of silicon (SiO_2), is heated to a very high temperature with coal or coke, the carbon deprives the silica of its oxygen and combines with the silicon to form carborundum, according to the chemical equation $SiO_2 + 3C = 2CO + SiC$. At very high temperatures carbon has an immense affinity for oxygen and can

remove it from other oxides. Part of the carbon unites with the oxygen taken from the silica and forms carbonic oxide gas.

The manufacture of carborundum is conducted by mixing sand, sawdust, and coke finely powdered and placing it in a rectangular brick box or furnace. Through the ends of this protrude two thick rods of arc-light carbon by means of which an electric current is conveyed through the mass which heats it intensely (see Fig. 1). The temperature rapidly rises and the chemical action sets in at 1950° C. The carbonic oxide which results escapes through the bricks and is allowed to take fire and burn on the outside. After the process is complete the furnace is dismounted and the carborundum is found as a mass of intensely hard crystals in the interior. These are crushed and sorted out into powders of various degrees of fineness. The process takes twenty-four hours to complete in each furnace. It is carried out on a large scale near Niagara Falls, U.S.A., in furnaces which produce more than 10 tons per day, using 3,000—4,000 electrical h.p. generated by the Falls (see Plate 2, upper diagram).

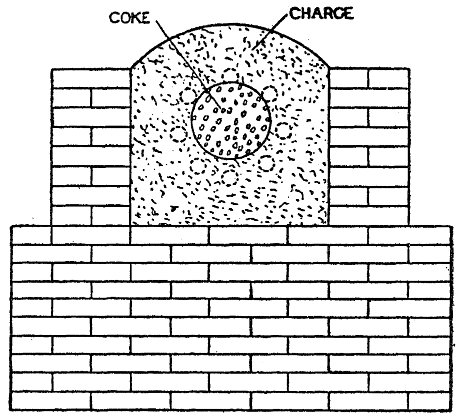


FIG. 1.—A Transverse Section of Acheson's Carborundum Furnace. The charge consists of a mixture of sand, sawdust, and coke packed into a sort of brick box, through the ends of which protrude two coke or graphite rods to convey the current. (See also Plate 2.)

Another similar electrothermal industry of large proportions is the manufacture of calcium carbide, so much used for the production of acetylene gas.

Just as carbon can deprive silica of its oxygen at a high temperature and form the carbide of silicon, so it can take the oxygen from calcium oxide or quicklime and form calcium carbide (CaC_2). If lime and coke are mixed together and an electric current passed through the mixture, the chemical action takes place at a certain temperature according to the following equation :—

$$CaO + 3\,C = CaC_2 + CO.$$

The resulting calcium carbide when put into water produces acetylene (C_2H_2) gas and hydrated lime.

$$CaC_2 + 2\ H_2O = CaH_2O_2 + C_2H_2.$$

The manufacture of calcium carbide is conducted on a vast scale at Odda, in Norway, using many thousands of electrical horse-power taken from lakes lying 1,300 feet above Odda. It is also conducted at many other places, and is now one of the most important of the electrothermal industries. Calcium carbide can be combined with nitrogen to form a substance called calcium cyanamide or nitrolim, which is used as a fertiliser or manure for the soil. This substance, when acted upon by water in the soil, is resolved into ammonia (NH_3), and carbonate of lime, and the ammonia is essential for the promotion of vegetable growth. Hence, this production of nitrolim has become an enormous industry. The nitrogen required is prepared from liquid air, which consists chiefly of liquid oxygen and liquid nitrogen. These can be separated by their different boiling points, since the nitrogen distils off first when the liquid air is allowed to boil. The nitrogen gas is then passed over intensely heated calcium carbide and combines to form the calcium cyanamide ($CaCN_2$). About 150,000 tons of this material are now prepared every year in factories in Norway, Sweden, Germany, France, Japan and Canada. The output from Odda, in Norway, alone is 75,000 tons.

In this connection another process should be mentioned which is also electrothermal, viz., the production of nitric acid from the air. The air consists chiefly of a mechanical mixture of oxygen and nitrogen gases chemically uncombined. They can be combined by passing air through an electric arc, which intensely heats them, and we have then compounds called oxides of nitrogen formed. If these gases are acted upon by air and water, they are converted into nitric acid, and this can be combined with soda or with lime to form nitrates of sodium or calcium.

These substances are very important fertilisers and are necessary for soil treatment in agriculture. Sodium nitrate occurs in nature as Chili saltpetre, and potassium nitrate as ordinary saltpetre. Nitric acid is an essential ingredient in the manufacture of all explosives.

Owing to the increasing demand the supply of natural Chili saltpetre is not equal to the world's requirements and, accordingly, of late years

great attention has been paid to methods of "fixing" atmospheric nitrogen, so as to prepare nitric acid.

One such process, known as the Birkeland-Eyde, is carried out on an immense scale in Norway in electric furnaces. An electric arc is formed in a narrow chamber by means of an alternating current of electricity, and by the action of a magnetic field this arc is spread out into a thin circular sheet of flame. Air is forced through this arc and a certain proportion of the nitrogen is converted into nitrogen oxides. The heated gases are quickly cooled and led up a tower filled with lumps of quartz or granite down which water trickles. The result is to produce a dilute nitric acid, which is then combined with lime to form nitrate of lime.

About 400,000 h.p. obtained from water power are employed in Norway in producing nitric acid by this Birkeland-Eyde process, yielding some 180,000 tons annually. This electric arc process, however, yields merely a dilute solution of nitric acid, and effects only the combination of a small fraction of the nitrogen and oxygen present in the air which passes through the arc. Hence it is uneconomical to carry out in any places at which power cannot be obtained very cheaply, as it is in Norway from water power. In 1913, Haber, in Germany, invented a process of making ammonia by compressing hydrogen and nitrogen gases under great pressure, to more than $1\frac{1}{2}$ tons per square inch, and passing them over certain substances called catalysers which cause the hydrogen and nitrogen to unite chemically and form ammonia gas. This can then be chemically converted into nitric acid. In this manner the Germans prepared the nitrates required for explosives during the European War of 1914—1918, and in 1918 they prepared by it about one million tons of ammonium nitrate. Quite recently, however, a French chemist, M. Georges Claude, has improved this Haber process by using much higher pressures up to 7 tons on the square inch, and so has greatly increased the percentage of nitrogen and hydrogen combined, raising it from 10—12 per cent., up to 30 per cent. M. Claude is now able to produce by this means $1\frac{1}{2}$ tons of ammonia per day.

The production of nitrates and nitrides has thus become an enormous industry, and but for Germany's internal resources in this respect the European War would probably not have lasted a year.

In the above cases the electric current acts merely to produce heat, and so brings about chemical reactions which only take place at a high temperature. There are some technical processes in which a current not only generates heat, but by an actual chemical decomposition or electrolysis liberates some required element from a compound.

An excellent illustration of this is the extremely important industry of preparing the metal aluminium from its compounds. The oxide of

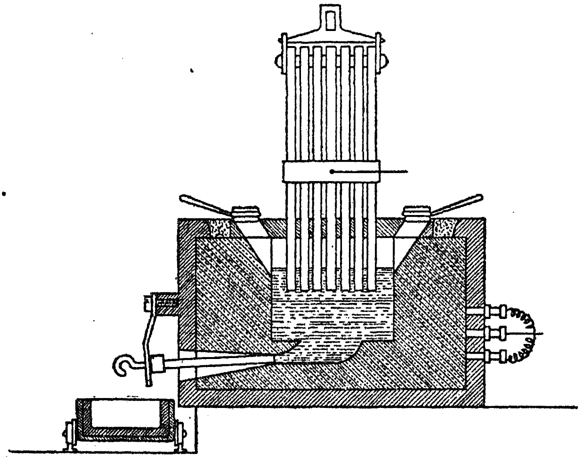


FIG. 2.—A Section of an Aluminium Reduction Pot. The seven straight rods in the upper part are the carbon electrodes by which the electric current is brought into the fused mass of alumina and fluorides. The spigot on the left-hand bottom side of the pot is for drawing off the reduced metallic aluminium.

aluminium called alumina (Al_2O_3) is one of the most abundant substances in nature, chiefly occurring in combination with silica to form various kinds of clay and earth-crust materials. The metal aluminium is of great value on account of its low density (about 2·6) as compared with other metals. Hence, in a pure form or alloyed with other metals it is essential for the manufacture of all parts of aircraft, aeroplanes and dirigible balloons.

Aluminium has, however, an intense chemical affinity for oxygen, and until the discovery of an electrothermal process for separating them the production of the pure metal was very costly.

Two young chemists, Hall in America and Héroult in France, almost simultaneously discovered a practical method for producing aluminium now used on an immense scale. It was found that pure alumina (Al_2O_3) will dissolve in a mixture of melted cryolite and fluorspar. The former is a double fluoride of aluminium and sodium and the latter, commonly called Blue John, is a fluoride of calcium. These two last materials in certain proportions are melted in an iron pot lined with carbon. The melting takes place at about 850° C. to 900° C. Finely powdered alumina, prepared from a mineral called bauxite, is then put in and an electric current sent through the fluid by means of a carbon rod dipping into it (see Fig. 2). This heats the material and keeps it fluid and also separates out the metallic aluminium, which falls to the bottom of the pot and is drawn off at intervals. The cryolite and fluorspar undergo no change, and it is only necessary to add more alumina from time to time and tap off the metal. About half the power supplied goes to keep the mass fluid and the remainder to produce the decomposition.

The process essentially depends upon the fact that the pure liquid metal is a little denser than the fluid and, hence, falls to the bottom of the pot. This Hall-Héroult process is carried out on a great scale at Niagara Falls, U.S.A., by means of electric current supplied by the electric power houses there. It is also conducted at Neuhausen at the Falls of the Rhine in Switzerland, and at Loch Leven in Scotland by the British Aluminium Company, who take their power from the Falls of the Foyers on Loch Ness, using more than 30,000 h.p. (see Plate 2, page 187). Each pot in the electrolytic process takes a current of 7,000 to 10,000 amperes at 5 volts, and a number of pots are worked in series. At Niagara each pot takes 65 h.p. and yields 112 lbs. of aluminium per day.

Before the invention of this process the total production of aluminium in the world was only 3 tons per annum, and the price was £2 16*s.* per lb. The electrolytic process produced 12,000 tons per annum in 1906, and the price had fallen to 1*s.* 10*d.* per lb. During and since the European War the price has risen considerably, but the production has enormously increased on account of the demand for aircraft manufacture.

A fourth electrothermal industry of increasing importance is the electrical manufacture of graphite, founded on a discovery of Mr. E. G. Acheson.

The element carbon exists in three forms in nature, viz., amorphous, as charcoal, coke, coal, or lampblack; crystalline, as diamond, and in a third form called graphite, represented by plumbago or so-called black-lead. All forms of carbon tend to pass into graphite when sufficiently heated. It is a characteristic of this substance, as shown in every *lead* pencil, that it will mark paper. The ordinary carbon rods used for the production of the electric arc are of amorphous carbon, viz., coke or lamp-black. If we test the crater end of a carbon which has been used for the production of an electric arc for some time, it will be found to be converted into graphite and will mark paper.

Acheson discovered that the change from amorphous carbon to graphite is greatly assisted by the presence of a small quantity of silica or of ferric oxide. He considers that the first effect of the high temperature is to form a carbide of silicon or carbide of iron, and then, at a still higher temperature, these carbides are decomposed and deposit the carbon in graphitic form.

Hence he found that, if powdered anthracite coal mixed with a small proportion of sand is electrically heated, a large proportion of it is converted into graphite. Also, if arc light carbon rods have a small proportion of ferric oxide mixed with them in making and are then heated to a high temperature in an electric furnace, the rods are converted into graphite.

These graphite rods in large sizes are much used as the arc electrodes in the arc furnaces presently to be described. Graphite is also used as a lubricant, and there is a great use for it in making plumbago crucibles.

Graphite occurs naturally in the earth's crust in three forms, flaky, fibrous and amorphous, as veins or nodules, mostly in igneous rocks The world's production of natural graphite has been recently about 140,000 tons per annum of all kinds, but the electrical Acheson process has of late contributed about 6,000 tons per annum and is steadily increasing.

The great advantage of the artificial process for the manufacture of graphite electrodes is that the amorphous carbon, coke, lampblack, etc., can be moulded into the desired shape by being mixed with tar or syrup,

then baked, carbonised and afterwards entirely converted into graphite by electrical heating.

Another application of direct resistance heating is in the electric reduction of iron ores to metallic iron. In the ordinary hot-air blast-furnace iron is obtained by smelting together iron ore, which is a crude ferric oxide or carbonate, with coke and lime. The carbon at a high temperature reduces the oxide of iron, and the lime combines with the silicates and phosphates to form a liquid slag. The iron runs to the bottom of the hearth and is drawn off at intervals and cast into bars called *pigs*.

In the electric furnace the same mixture of iron ore, coke and lime is heated by passing a powerful electric current through the mass, and the molten iron sinks down into a hearth, from which it is tapped off.

In the combustion blast-furnace it has been found possible to produce 1 ton of pig-iron by the use of 16 cwt. of coke ; of this 6·5 cwt. are required to effect the reduction of the oxide of iron, and 9·5 cwt. to produce the heat.

Hence the electric process, which abolishes the need for combustion, can only, at most, save 10 cwt. of coke, and its economy depends on the relative cost of 10 cwt. of coke and of the 2,000 to 2,500 Board of Trade units of electric energy which are found necessary for the production of 1 ton of pig-iron by the electrical process.

An electric furnace for pig-iron production was invented by Keller Leleux & Cie. and is used at Livet and Kerrousse in France, but the manufacture cannot compete with the blast-furnace production unless the price of electric energy is less than 0·25*d.* per unit.

Hundreds of tons of pig-iron have, however, been prepared by it, and any objections to its use are solely on account of cost.

There are other extremely important parts of the iron and steel industry in which electric heating is of steadily increasing value.

Pig-iron is the raw material out of which all other varieties of iron and steel are produced. It contains a considerable quantity of carbon, combined and uncombined, and many impurities, such as phosphorus, sulphur and silicon, which give it brittleness.

It is possible by certain processes to remove all these impurities and

produce nearly pure metallic iron. This material has a melting point near 1,500° C., and is rather soft and fibrous in structure. Iron combines with carbon to form certain carbides of iron, and these dissolve in, or alloy with, pure iron.

The material we call carbon steel is such a solid solution or admixture of a carbide of iron (Fe_3C) called *cementite* with pure iron (Fe), called *ferrite*. The total amount of carbon may vary from 0·3 to 1·57 per cent. Steel may, therefore, be said to be the connecting link between pure iron (wrought iron) and pig iron (cast iron).

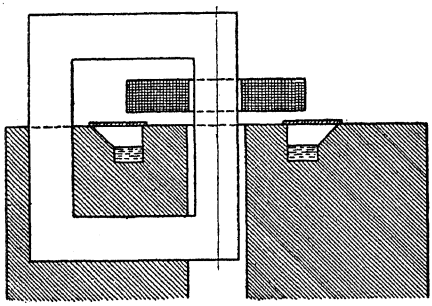


FIG. 3.—A Section of a simple form of Induction Electric Furnace. The white rectangle represents a core made of sheets of iron. The cross-hatched part is the section of a primary magnetising coil, and the grooves in the shaded part are the sections of a circular trough in some insulating, but refractory, material.

Certain kinds of carbon steel have the property of hardening when heated above certain temperatures and then suddenly cooled in water or oil, called quenching. One theory of this is that in the heated steel the carbide is dissolved or diffused throughout the mass. If cooled slowly, the carbide separates out in little aggregations. The result is a soft or annealed steel, according to the temperature of quenching. If the metal is quickly cooled, the carbide is fixed or gripped in its uniformly diffused state, and this alloy of iron and carbide of iron is extremely hard. It is this property which gives steel its value for making tools, knives and cutting instruments.

It has been found of late years that other extremely useful properties can be given to carbon steel by alloying it with small proportions of other metals, such as nickel, chromium, tungsten, vanadium, molybdenum, etc., and these are called alloy steels. For instance, a certain type of vanadium steel has the property of withstanding violent vibrations and blows better than carbon steel, and the present-day manufacture of motor cars would be impossible without it. Also, some tungsten steels can be made extremely hard, and are not softened by heating. These are used to make high-speed or quick-cutting tools. Again, nickel steels and

chromium steels of certain kinds have special properties valuable in making armour plates and shells for battleships. These alloy steels are

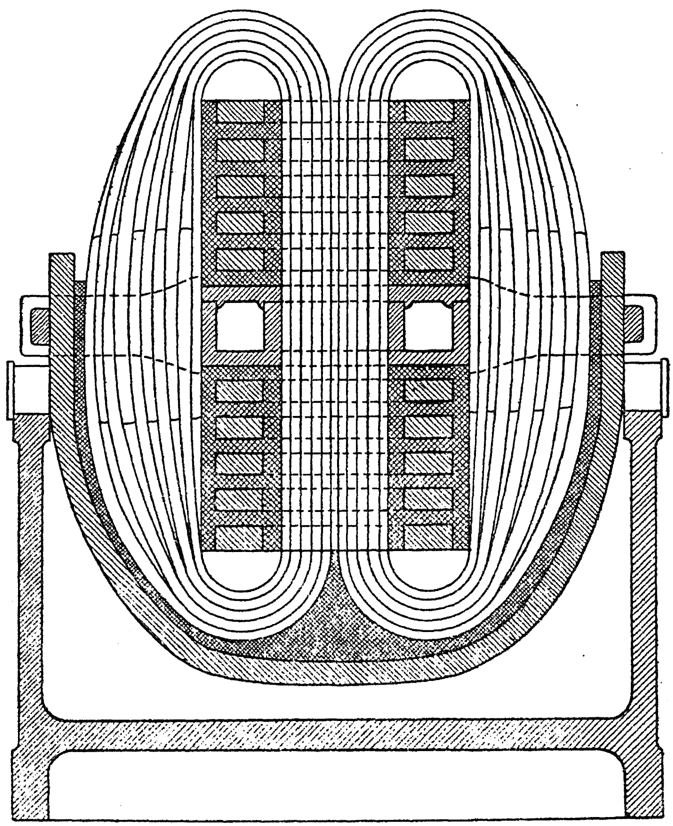


FIG. 4.—A Section of a Ferranti Induction Electric Furnace. It is in fact a transformer with a secondary circuit consisting of a trough formed of some insulating, but refractory, material. The metal to be melted is placed in this trough, and the induced electric currents generated in it raise it to a high temperature.

produced now on an immense scale in France, the United States, Germany and Great Britain in electric furnaces.

There is a type of electric furnace called an induction furnace, which has a useful field of operations in steel metallurgy. The first suggestion for it was given by Mr. S. Z. de Ferranti. A large rectangle of laminated

iron has a primary coil of wire wound round one side through which an alternating current can be sent (see Figs. 3 and 4). The iron is, therefore, traversed by an alternating magnetic flux. This rectangle of iron is linked with a secondary circuit, formed by an endless trough made of fire-bricks or magnesite. In this circular trough are placed lumps of iron or steel. If, then, the alternating current is started in the primary circuit, the lumps of steel in the trough, making electrical contact with each other, will form a closed secondary circuit linked with the iron core, and a current will be induced in it which will rapidly heat and melt the lumps of steel. In order to secure the conductivity of this secondary circuit, it is usual to put an iron ring into the bottom of the trough, which ensures the starting of the secondary current.

When the lumps of steel are melted, various ingredients can be added to the steel to alloy it or purify it, and a final desired composition attained.

The advantage of this method of heating by an induced current is that it avoids the use of any electrodes of carbon or other material to introduce the current, which may in turn affect the final composition of the steel.

There are various forms of this kind of induction furnace, such as that invented in 1900 by Mr. F. A. Kjellin, a Swedish engineer, and another type, using three-phase currents, introduced by Röchling and Rodenhauser in Germany.

Induction furnaces on this plan can be made to hold 8 or 10 tons of steel in their troughs, and are erected on trunnions, so that, when the charge is melted and the treatment finished, the contents can be tilted out and cast in moulds or pigs.

There are many cases in which the direct passing of an electric current through the object to be heated cannot be allowed or achieved.

It is then necessary to pass the current through a resistance generally made of carbon or nichrome and heat the object by radiation from it.

It is not possible in this way to obtain such high temperatures as by direct resistance heating, because we are limited by the melting point or volatilising temperature of the resistor. Such an electric furnace consists of a box or oven made of very refractory material, fire-clay, magnesia or silica bricks, or diatomaceous bricks. The outside may be lagged with

slag-wool, a kind of artificial asbestos, and rendered compact by an iron casing or iron bands.

In the interior are arranged bars or wires of refractory material as resistors. It is not convenient to employ spirals of wire, because if these spirals are hung vertically, then, when they become white hot, the turns tend to stretch out at the top and come together at the bottom parts, and the result is a "short circuit" or "burn-out."

Some makers put the spirals horizontally and lay them in grooves of

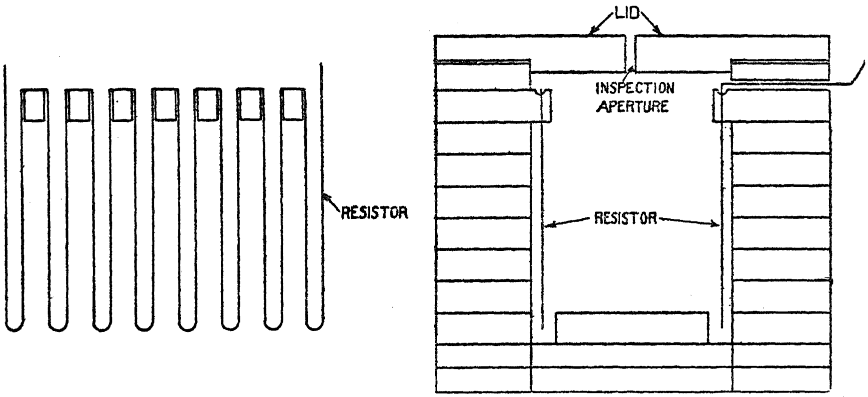


FIG. 5.—A Fleming Electric Resistance Furnace. The right-hand view represents a section of a kind of brick box built of highly refractory and heat-insulating bricks. In the interior, on their sides, are suspended loops of nichrome wire, called the "resistor," through which the electric current passes and produces heat. Objects to be heated are then placed in the interior.

the furnace lining, but at high temperatures the silica or magnesia is apt to render metal in contact with it rotten and the result is a fracture.

The author found after extensive experiments that the best method to employ was to arrange a suitable resistance wire in loops or zig-zags and support this wire on projections of refractory insulating material so that the resistance wire takes the form of a series of loops hanging down close to the interior walls of the furnace but not touching them. The wire is then quite free to expand and contract, and there are no joints, but the thickened ends of the wire are brought out through holes in the furnace wall to cables which supply the electric current (see Fig. 5). Such a resistance furnace is best worked with alternating currents because then,

by the employment of a transformer, we can obtain the large currents at low voltage which it is most safe and convenient to use in electric furnaces.

By the use of nichrome wire of No. 10 or No. 14 S.W.G. size, temperatures of 900° C.—1,200° C. can be maintained for long periods of time in the furnace.

As the temperature rises it is necessary to reduce the current by a choking coil because much less power is required to maintain than to obtain a given temperature. The economy of such furnaces, in fact, wholly depends upon the degree to which heat can be prevented from leaking out through the walls or lid of the furnace.

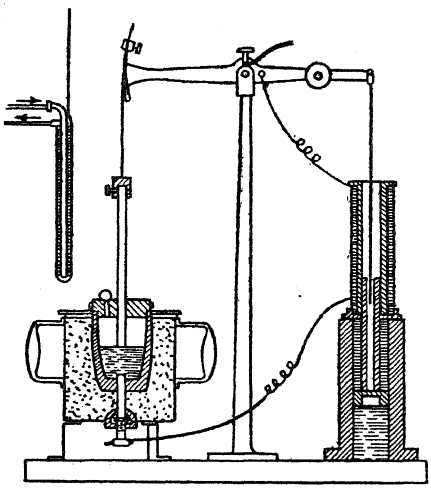


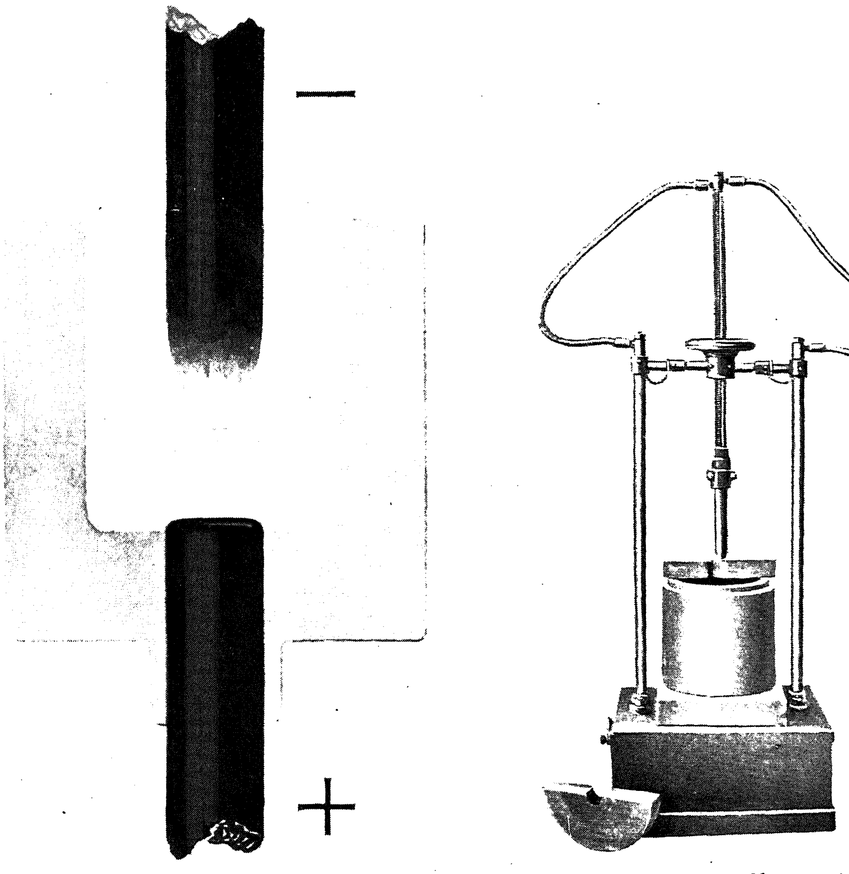
Fig. 6.—An Electric Arc Furnace as first made by Sir William Siemens in 1879 for smelting iron and steel.

Resistance furnaces having the resistance wires or strips buried in the walls of the furnace are used in muffles and for heat treatment of materials in metallurgy and chemistry, and arrangements can easily be made so that a desired temperature is constantly maintained by the use of a thermometer which cuts off the current when the temperature rises beyond a certain point, and starts it again if it falls below it. A device of this kind is called a thermostat.

We must next consider a type of electric furnace called an arc furnace, which is, perhaps, the most widely used of any form in iron and steel manufacture.

Sir W. Siemens, in 1879, was the first to construct an arc furnace as follows: Through the bottom of a clay or plumbago crucible he passed an arc lamp carbon and connected it to one terminal of a dynamo. He filled the crucible with lumps of steel and brought down on the top of the mass an iron or carbon rod attached by a wire to the other pole of the dynamo. An electric arc was then formed between the tip of this rod and the mass of metal and the heat produced soon melted the iron (see Fig. 6

PLATE 3.

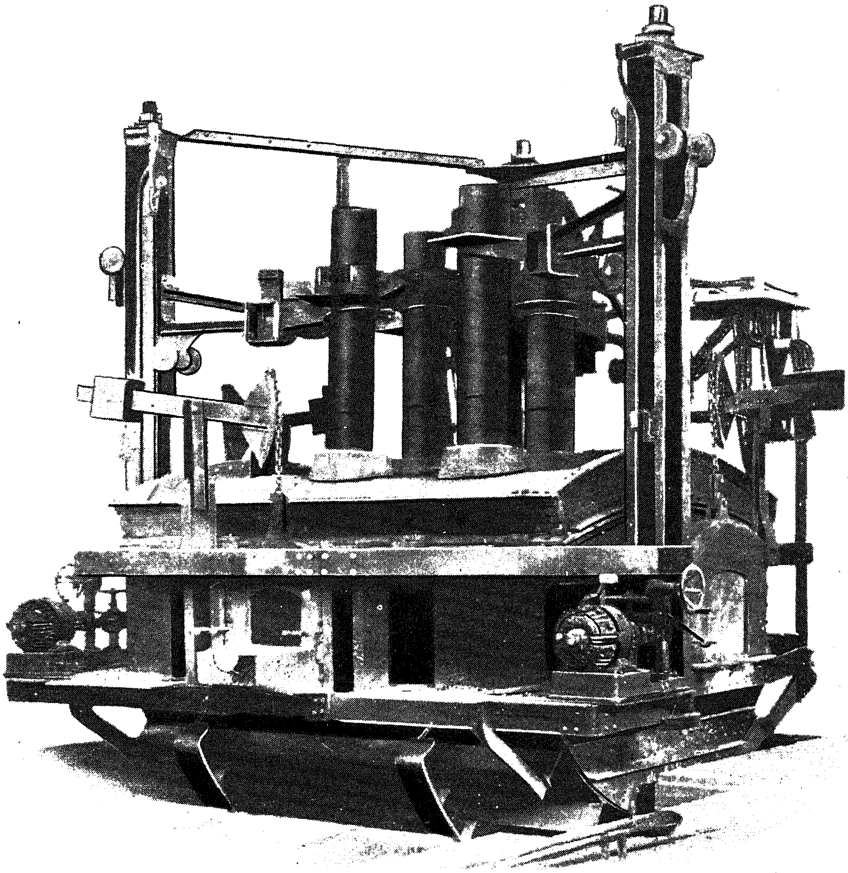


[*By permission of Messrs. Marryat and Place, Ltd.*

An Electric Arc Furnace of Siemens Type, as made by Messrs. Marryat and Place. It consists of a crucible of magnesite or lime through the bottom of which passes a graphite rod, which forms one electrode of the arc, and the other is a similar rod which can be raised and lowered so as to form an electric arc in the interior of the crucible, and thus produce an intense heat for smelting metals.

[*To face page* 200.

PLATE 4.



[*By permission of* " *Conquest.*"

An Electric Arc Furnace of Héroult Type, capable of melting 10 tons at one heat. The massive carbon electrodes, which are five feet long, are clearly shown, as also the mechanism for raising and lowering them. When the smelting is complete, the furnace is tilted, and the molten metal run out into a ladle. An electric furnace requires no chimney, and there are no waste gases to be removed. Immensely high temperatures are easily reached, and are under complete control. (See page 202.)

[*To face page* 201.

and Plate 3). Using a current of 36 amperes Siemens found he could melt 22 lbs. of steel in an hour. His estimate of the economy of the process was that 1 lb. of coal burnt in the furnace of a steam boiler supplying an

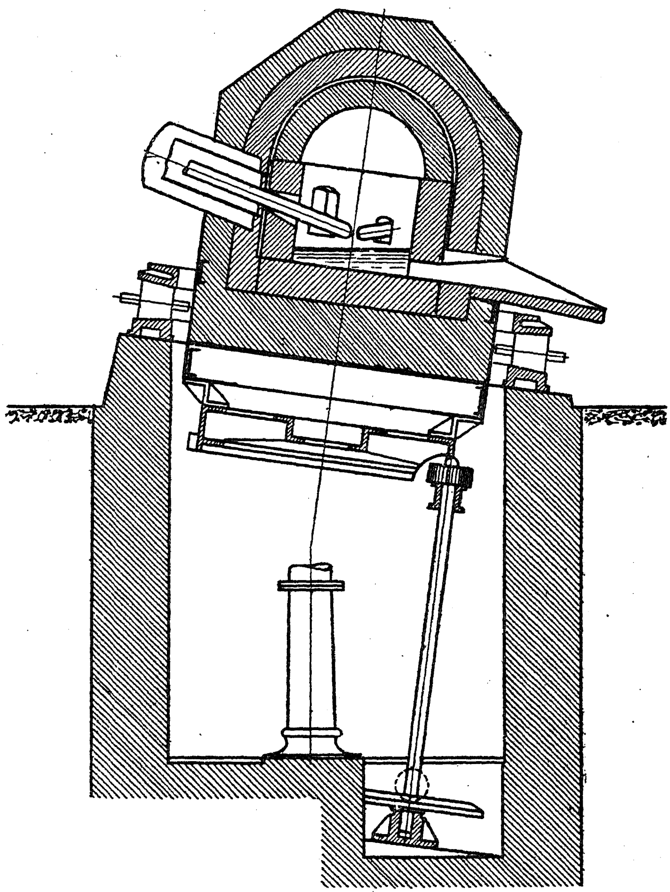


FIG. 7.—Section of a Stassano Electric Arc Furnace.

engine which drove the dynamo would melt 1 lb. of steel in the electric furnace. This proved that the latter could compete in economy with the gas regenerative furnace. Nothing more was done until 1898, when Major Ernest Stassano, of the Italian Army, devised a form of arc furnace for melting steel. This consisted of a drum-shaped iron vessel lined with

refractory material through the sides of which large carbon rods passed, between the ends of which a powerful electric arc was formed (see Fig. 7). The steel to be melted was placed in a basin-shaped hearth of the furnace under the arc, and the whole furnace could be inclined or rotated to mix up the charge when it was melted and tilt it out. An improved type of electric arc furnace was, however, invented by M. Paul Héroult, who

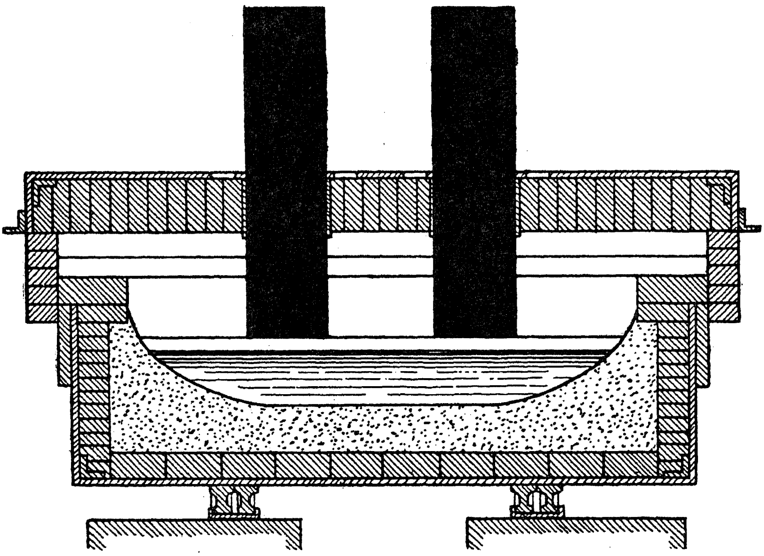


FIG. 8.—A Héroult Electric Arc Furnace. The black bars represent the massive carbon electrodes which convey the electric current, and between them and the heated charge a powerful electric arc is formed.

had previously become well known as one inventor of the electrolytic process for making aluminium.

The Héroult arc furnace consists of a basin-shaped iron vessel with a cover. This is lined thickly with refractory bricks of magnesite or dolomite. Through holes in the cover very large graphite rods pass. The furnace is arranged on trunnions so that it can be tilted to pour out the melted metal in the interior (see Fig. 8 and Plate 4). The massive carbons which project through the cover are insulated from each other and are connected to a powerful dynamo. These carbons can be raised or lowered by hydraulic or electric gearing.

The furnace is worked in the following manner: A charge, consisting of scrap steel, pig iron, iron ore and lime, is put in the interior and the large carbon electrodes are brought down to touch it. An electric arc is then formed and before long the mass of material is melted. The slag rises to the top and can be tilted off by the spout. We can then add either carbon to the metal or oxide of iron to bring the whole mass to a desired carbon-iron composition; in other words, can prepare a steel of a certain composition. When the treatment is complete the charge is tilted out and cast.

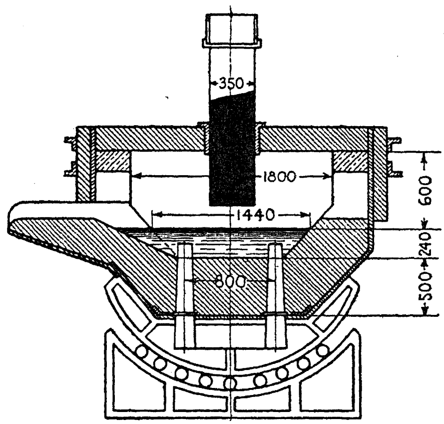


FIG. 9.—Girod Electric Arc Furnace. The furnace is supported on balls in a semi-cylindrical base to facilitate tilting out the fused charge. The black rod is the carbon electrode.

In another type of arc furnace devised by M. Girod, there is only one large graphite electrode, which passes through the cover of the furnace, and the other electrode consists of a number of steel rods which pass through the bottom or hearth of the furnace (see Fig. 9). These rods may be made hollow and water passed through them to keep them from melting. The advantage claimed for this single-carbon furnace is that there is less chance of a short circuit occurring than when two carbons are used, and also that a combined resistance and arc heating can be effected with it. One great use of such arc furnaces is for using up scrap steel and iron and preparing from it a good quality of cast steel of uniform composition. In engineering works there is a vast accumulation of iron and steel scrap borings, filings and chunks, which vary in composition. Also disused parts of old machines and imperfect iron castings accumulate. This material can all be melted together in an arc furnace and either decarbonated by adding iron oxide or carbonised to a known desired degree to prepare a certain steel.

Another great use is in the preparation of ferro alloys, or alloys of iron with known quantities of rarer metals. It has already been mentioned

that steel having in it a certain small percentage of some metal such as tungsten or vanadium has valuable qualities.

It is not easy to add to a large crucible full of molten steel just the right quantity of a small amount of rare metal and yet mix it thoroughly so that each portion shall have the same composition. It is best done by first preparing an alloy of iron with a large percentage in it of the rare element and then adding the right weight of this alloy to the bath of steel of known weight so as to produce a total quantity of steel having the required small percentage of rare metal in each part.

This calls for the preparation of alloys of iron with large, but known, percentages of vanadium, tungsten, chromium, etc.

These ferro alloys are manufactured in large quantities in the Haute Savoie, France, where water power is abundant. The Girod Electro-metallurgical Company, at Ugine, France, is using 20,000 h.p. or more for their production.

One of the alloys most in demand is ferro-silicon, an alloy of iron with 10, 20, 50 or 80 per cent. of silicon. This alloy is used to bestow hardness and fluidity on cast iron by adding a certain proportion of it to the molten iron just before casting.

Five or six thousand tons of it are produced per annum at the Girod works alone. Another important alloy is ferro-tungsten. It is employed in the production of high speed tungsten steel, which, when hardened, does not soften even at a red heat and can, therefore, be used to make metal-cutting tools which work at a high speed or cut much faster than ordinary carbon steel tools. This steel and various other high-speed steels are now made in Great Britain. The demand for it has greatly increased since 1900, when the Bethlehem Steel Company's exhibit at the Paris Exhibition drew attention to the subject. In the same manner ferro-chromium is used in making steel for armour plates and shells to bestow hardness. Ferro-vanadium is another valuable alloy. It is used in making the steel employed for axles, gears and shafts in motor cars, as it is found to give greatly increased power of resisting shocks and vibrations, even when the vanadium is present in the finished steel in only 0·2 to 0·8 per cent. In the manufacture of these alloys the induction furnace is also used as it enables an alloy to be produced

which is not contaminated with any excess amount of carbon, whereas in the case of arc furnaces this contamination is possible. At the present time another great use of the arc electric furnace is in the production of steel direct from pig iron and scrap iron. For this purpose the excess of carbon and other impurities, such as phosphorus and sulphur, in the pig iron have to be removed. This is done by the addition of oxide of iron to the melted pig, which gives up oxygen and removes the carbon, whilst lime is also added to form a fusible slag. When the metal is sufficiently purified a known percentage of carbon is added to it in the form of carburite or a highly carbonised iron. The removal of impurities is assisted by blowing air through the metal, as in the Bessemer converter. The resulting steel is then tipped and cast into bars.

In the electric furnace the sulphur and phosphorus can be almost completely removed and an even better quality of steel produced than by the crucible process.

Electric furnaces are now at work producing as much as 200 tons of steel per day per furnace.

Whilst not replacing entirely all the time-honoured gas or fuel furnace methods in the iron and steel industry the electric furnace, both in arc and induction form, is now acknowledged to be a most valuable addition to our resources, but mostly so in countries in which water power is abundant, but coal less so, or scarce, such as Canada, Switzerland, France and Norway.

We shall next consider some of the applications of electric heating in domestic life and discuss its possibilities.

We require heat in our houses for three purposes, viz., house-warming, cooking and water heating.

For all these purposes electric heating is available, and suitable apparatus of many types designed, but they come into competition with existing methods using coal, oil or gas as fuel.

Experience has shown that whatever may be the indirect advantages of using a new method, it makes slow headway unless it is at least comparable in cost with older and existing methods. Hence, the first questions asked in reference to electric domestic heating are, does it work ?—that means, is it effective ?—and next, how does it compare in cost with

coal or gas? As regards the first question, it is possible to say, confidently, that invention has brought us to the stage at which everything in the way of domestic heating and cooking can be done as well and, in some respects, better by electric heating than by combustion heating, whilst there are vast advantages in cleanliness, freedom from products of combustion, and diminished labour in connection with the electric heating. As regards costs it is not possible to speak so definitely at the present time. The great European War (1914–19) has upset all previous calculations by raising the price of materials and labour, whilst the frequent strikes and continually rising wages bills in all industries make strict comparisons very difficult. We shall, however, give such figures as are possible.

Let us consider first the heating of rooms. In order to be comfortable indoors the air temperature must be raised to 60° F. or 65° F. If it falls below 45° F. or 50° F. we feel chilly, and if it rises above 65° F. or 70° F. we generally complain of the heat. We here give Fahrenheit temperatures, as these are usual in domestic life.

We are, however, very sensitive to the amount of moisture in the air. If it is too dry or too moist we experience sensations of enervation. A comfortable amount is about 1 per cent. of water vapour. Thus, the air in a room having a capacity of 1,000 cubic feet should contain 10 cubic feet of water vapour. Our comfort is also dependent upon this air being, as we say, fresh, that is, not contaminated with carbonic dioxide gas or organic matter, the products of respiration.

Hygienic air heating, therefore, requires that the air of inhabited rooms shall not only be within certain temperature limits, but shall be continually renewed. Air is very diathermous—this means that radiant heat passes through with but little absorption. The only way, therefore, in which it can be heated is by coming in contact with a warm substance, solid or liquid. Heat is diffused through a mass of air, chiefly by convection, which means that air which has been heated by contact with a warm substance rises or moves away on account of its decreased density and makes room for colder air to come in its place. Hence, there is a circulation of air carrying heat with it. At the standard temperature (viz., 60° F.) 12·35 cubic feet of air weigh 1 lb. Hence, 1,000 cubic feet

of air weigh very nearly 80 lbs. The air, therefore, in quite a small room may weigh from 100 to 200 lbs.

The specific heat of air is 0·2375. This means that it requires only about one-quarter the amount of heat to raise 1 lb. of air 1° F. that it does to raise 1 lb. of water 1° F. This last quantity of heat is called a British thermal unit (B.Th.U.) Hence, to raise 80 lbs. of air or 1,000

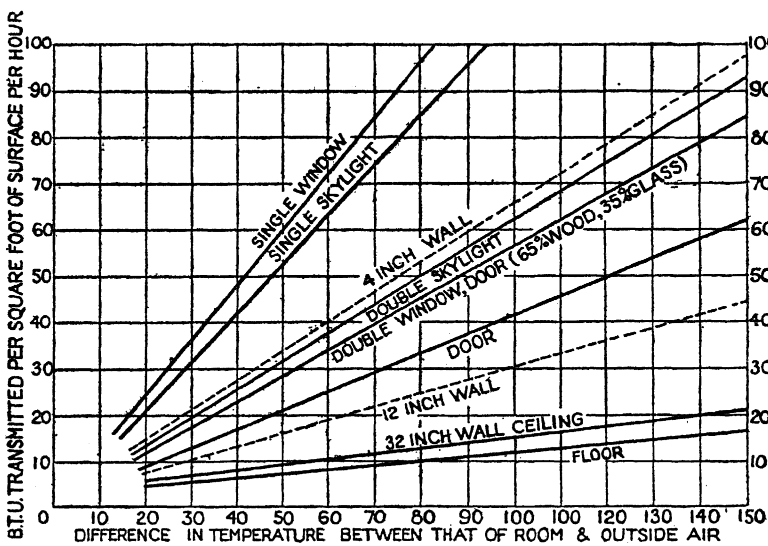


FIG. 10.—Curves showing the Heat Leakage reckoned in British Thermal Units per square foot per hour passing out through various house surfaces, corresponding to certain differences between indoor and outdoor temperatures. It is easily seen that single glazed-glass windows are the cause of great heat loss from our houses.

cubic feet 1° F. requires $80 \times 0{\cdot}2375 = 19{\cdot}24$ B.Th.U. This amount is equal to 5·56 watt-hours.

Suppose, then, that 1,000 cubic feet of air has to be raised from 32° F. to 65° F. or through 33° it would require heat energy equal to 186·45 watt-hours to 0·186 Board of Trade unit to do it.

Consider a room having a capacity of 2,500 cubic feet. To heat the air in it from 32° F. to 65° F. would theoretically require heat energy equal to about 0·5 Board of Trade unit.

The air in a room has to be renewed, at least, twice an hour to keep the

place ventilated and prevent it from feeling "stuffy" or "close." We all know the unpleasant feel of a bedroom which has no fireplace in it, in the morning, unless the sleeper in it has kept the window partly open. Hence, for air heating alone a room of the above size will require, at least, one Board of Trade unit of energy. But this is not sufficient. The heat given to the air rapidly leaks out through the walls, ceiling and windows. Our rooms and houses are far from being heat-tight or heat-insulated as they are usually built. Double walls and double windows are a great preventive against this heat leakage.

Some curves given to the author by Mr. Huntly, of the Dowsing Radiant Heat Company, from observations by Mr. A. R. Wolff, show the remarkable loss of heat in this manner. The curves give by their ordinates (height) the heat energy in British thermal units per square foot per hour leaking through the various boundary surfaces of houses for certain differences of temperature between the inside and outside air. It will be seen how greatly double walls and double window glass with air space between reduce this leakage (see Fig. 10).

Taking this into account, we may say that a room having a capacity of 2,500 cubic feet, which corresponds to a floor area of about 20 × 12 square feet, and height of 10 feet, would require heat energy equal to at least two Board of Trade units per hour to be given to it to keep it at a comfortable temperature.

Experience seems to show that to keep a room of this size warm by a gas fire it would be necessary to have a stove which consumes 50 cubic feet of gas per hour, whilst a coal fire in it running all day for twelve or fourteen hours will use 40 lbs. of coal per day, or about 3—4 lbs. per hour.

The coal fire cannot, however, be started at a moment's notice, and if only used a short time is far less economical than when kept going all day.

We have next to describe the methods by which this heat can be furnished electrically. There are two ways. One called convection heating, and the other radiant heating. In the non-luminous electric convector there are wires or resistors which are placed in an ornamental box or frame. An electric current is passed through the wires heating them, but not visibly red hot. The air passes over these hot surfaces

and takes up heat and becomes itself warm. It is best to place such convectors at points where the cold air enters the room, which then becomes raised in temperature (see Plate 5, page 214).

In luminous or radiant heating we may employ a special type of tubular heating electric incandescent lamp introduced, first by Mr. H. J. Dowsing, or we may use nichrome wire spirals or wire wound over mica or fire-clay supports, which wire is heated to a bright red heat by the electric current (see Plate 5, page 214).

In the case of the luminous radiator the radiant heat does not heat the air directly, but it heats the furniture in the room and the bodies of the inhabitants, and these in turn heat the air by contact.

The radiant heat falling on the human body produces a sensation of warmth, but the air around us must be heated as well to produce comfort. Hence the best mode of electric heating for large rooms is a combination of the two methods convection and radiation. The radiant, or luminous, heating has a cheerfulness which is quite absent from the non-luminous or convection methods. In place of the heating lamps used in the Dowsing radiators, which are generally carbon or metallic filament lamps run at a rather low temperature to give them a long life, in some radiators bare nichrome wire wound on non-inflammable supports is used. In the Berry radiator these wire units are set in an upright position and the air passing over the incandescent wire produces variations of brightness which imitates a flickering flame.

In the lamp radiators there is an item of expense for lamp renewals which is absent from the wire radiators. These electric radiators are much used in bathrooms, small bedrooms, offices and ship's cabins not possessing a chimney and where a coal or gas fire cannot therefore be employed.

As regards relative cost, we have above given certain figures. We may say that for electric room heating we require to expend about 1 kilowatt in power for every 1,000 cubic feet of space. The large sizes of luminous radiator taking this power are, however, trying to the eyes from the amount of light given out. Hence to heat comfortably a room having 2,500 cubic feet of space, it is best to employ a 1 or 1·5 kilowatt luminous radiator, which may be placed in the fireplace, and a 1 or 1·5 kilowatt

non-luminous convector, which should be placed as far away as possible from the other at the opposite side of the room.

The electric heating system is admirably adapted for rooms used only occasionally, or for bedroom heating for an hour or two, but at the present prices neither electricity nor gas can compete with a coal fire or anthracite stoves for long hours (all day or all night) of use.

Its extension, therefore, depends on the reduction in price of the unit of electric energy. The house of the future will be built without chimneys, and with double walls and windows. The ventilation will be effected by electric fans or Tobin tubes with electric convectors in them and the dirt, dust and labour connected with the use of coal, or even gas, as a fuel will be entirely absent (see Plate 5, page 214).

Mention must next be made of the application of electric heating in domestic cooking.

Apart from boiling of water or heating milk and other liquids, a large part of the operation of cooking consists in exposing the edible material to such a temperature that, if of animal nature, the albumen in the flesh is coagulated, but not at such a temperature as to make it insoluble in the gastric fluids. Also other operations involve the partial conversion of starch into dextrine as well as the softening of animal or vegetable tissues by heat.

The heat for this purpose must be capable of a ready variation over a temperature from 100° F.—500° F.

The following are the temperatures which must be attained for various cooking operations. They are given on the authority of Mr. Senn, and are quoted from an excellent handbook entitled *Electricity for Everybody*, by Mr. R. Borlase Matthews* :—

Saucepans.

Fast boiling	212° F.
Simmering.	180°—190° F.

Ovens.

Roast beef.	300° F.
Roast mutton	310° F.

* Published by *The Electrical Press, Ltd.*, 37-38, Strand, London, W.C. 2.

Ovens—continued.

Game and poultry . . .	310° F.
Meat pies	290° F.
Pastry and cakes . . .	320° F.
Bread and puff pastry. . .	340° F.

Frying.

Fish	360°—375° F.
Meat.	370°—380° F.
Fritters	340°—375° F.
Whitebait	400° F.

In many operations such as baking meat, the temperature has to be high at first and quickly applied, so as to coagulate the albumen in the outer surface and seal in the juices, and then a little later the cooking should be continued at a much lower temperature.

Hence, every electric oven should be capable of quickly attaining a temperature of 400° F. at least in the interior and be under complete control.

The ordinary domestic cook is accustomed to use her hand as a thermometer by which to judge temperature. It is better, however, to fit the oven with a thermometer by which the internal temperature can be ascertained without opening the door.

Electric cooking apparatus may be divided into two broad classes.

First, that type in which the cooking is done in a special appliance, oven, kettle, or frying pan, having heating wires buried in the walls, placed in a double bottom, or embedded in an enamel on the bottom of the dish. An electric current passed through these wires, heats them, and therefore the food placed in the oven or pan (see Plates 5 and 6, pages 214 and 215).

The second class of electric cooker comprises a heater in which electrically heated wires in the interior raise an iron plate or other surface to a temperature near or above red heat and then ordinary cooking utensils, kettles, saucepans, or ovens, are placed over the heater or the heater put into the interior (Plate 6, page 215).

The objection to the first type of apparatus is that, generally speaking, if a heating wire burns out the whole appliance is useless until repaired.

On the other hand, the second type has the advantage that a second or spare heater can be kept, and the cooking operations are not entirely stopped by the burn-out of a single heating wire. Also the same vessels, kettles and saucepans, can be used that are employed in gas cooking. Nevertheless, there are good and durable appliances of both types on the market.

As a good example of the first type we may mention the electric oven of Bertram Thomas (see Plate 5). In this the walls of the oven are thickly

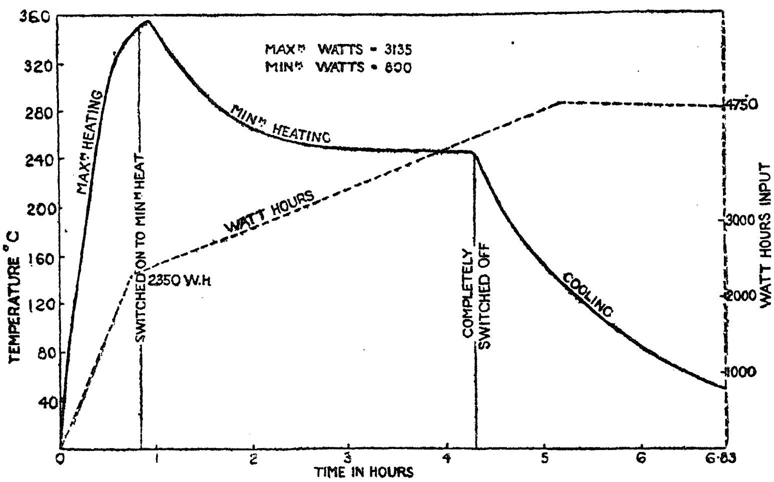


FIG. 11.—Heating and Cooling Curves for a certain Lagged Electric Oven, showing the time required to reach certain interior temperatures or to cool off from them.

lagged with heat non-conducting material and the heating wires or resistors are placed in them and controlled by two or three switches so as to give various temperatures. The maximum power which can be given is 3,135 watts, and the minimum 800.

The diagram in Fig. 11 shows the heating curves, or curves indicating the time required to attain certain interior temperatures or to cool off again, from experiments made by the author on a certain oven of this type.

An oven on the second system is well represented by the Berry "Tricity" oven. In this system there are one or more flat round iron boxes, each of which contains a heating wire wound on a mica frame. The heating wire is entirely enclosed in the iron box, and connecting wires,

by which the current is led in and out, are included in a flexible metal tube. This heater takes a current of about 8 amperes at 100 volts pressure, or, say, 800 watts. If the current is kept on the iron plate will gradually rise in temperature to nearly a dull red heat. On this plate can be placed a kettle or saucepan for boiling, just as if it were a gas ring, or a light oven of bright tinned iron can be placed over it. Such ovens generally have two heaters, one at the top and one at the bottom (see Plate 6). In this last type the loss of heat from the oven by radiation is diminished by the fact that the outer surface is bright, just for the same reason that we make teapots of bright polished metal.

In the special electric kettles or water boilers the heating wires are placed in the space between a double bottom. Care must, then, be taken not to switch on the current unless some liquid is placed in the vessel. On the other hand, the heating wire may be enclosed in a nickel-plated metal tube or immersion heater, which can be placed in liquid in any ordinary jug or glass, and will warm it when the current is sent through the heater.

The chief fault of much of the electric cooking apparatus at present is the liability of the heating wire to burn out unless very carefully handled, and the result is that the apparatus becomes useless until repaired.

Special repairs of this kind, owing to the rise in wages, are relatively far more costly than the first purchase. What is required is some form of heater which can be inserted by the user in the apparatus and thrown away, like a broken electric lamp, when it is burnt out.

Another very important point is the necessity for using low voltage in connection with cooking apparatus.

The current supplied to our houses for lighting is now mostly furnished at 220 volts. In an electric cooking apparatus, if a heating wire comes in contact with an outer case, a person may receive an electric shock which is startling, even if not dangerous. Hence low voltage is important. This can easily be done when the supply is by alternating current, as then it can be transformed down to 25 or 50 volts, whatever the voltage of supply. It is nothing short of a crime to place in the hands of ordinary domestic cooks electric cooking apparatus worked at 220 volts off one side of a 440 three-wire system of supply (see Chapter V.).

Another fault of much of the electric cooking apparatus in use at present is that it cannot take up energy fast enough so as to reach a high temperature quickly. This, however, is a matter of design.

The fact remains that electric cooking is at present a thoroughly practical matter, and there are large restaurants and institutions where the whole of the cooking is conducted by electric heating.

One immense advantage in household life is the cleanliness and small space required, and, also, that the cook does not have to stoop down as in the case of the ordinary coal- or gas-heated oven to inspect the food in it. An electric oven stands on a table breast high. There are no escaping hot fumes, as in the case of gas rings, and no chimney is, therefore, required. There is no soot and no flame, and, therefore, little need to clean the outside of vessels used.

Unless electric energy is supplied at very low cost, the heating of large quantities of water by it is not very economical. Water possesses the highest specific heat of any substance in nature. This means that it takes more heat to raise 1 lb. of water through 1° F. than it does to raise 1 lb. of any other substance through the same range of temperature. The heat required to raise 1 lb. of water 1° F. is called 1 British thermal unit (1 B.Th.U.), and this is equal to 0·294 watt hours.

Hence to raise 1 gallon (= 10 lbs.) of water from 60° F. to 212° F. requires 440 watt-hours of energy, or 0·44 of a Board of Trade unit.

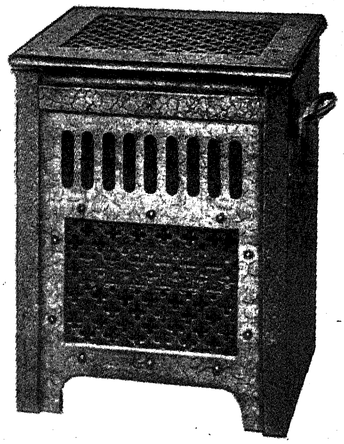
A cubic foot of water weighs 62 lbs. To provide 40 gallons of water at 110° F., or rather over 6 cubic feet of water, for a hot bath requires the expenditure of about 6 Board of Trade units, assuming that all the energy is employed in heating the water.

Experiments made by the author in 1910 and 1911, and described in his Cantor Lectures delivered before The Royal Society of Arts in 1911, showed that in electric kettles and water heaters we can utilise in heating the water between 80 and 90 per cent. of the electric energy supplied to the apparatus.* Hence we may say that between 6 and 7 B.T.U. will heat 40 gallons of water from 60° F. to 110° F.

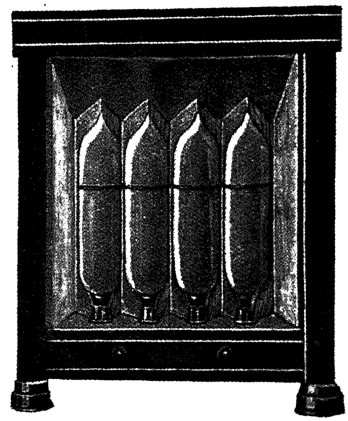
Before the European War of 1914–1918 electric energy was supplied

* Cantor Lectures on "The Applications of Electric Heating," *Journ. Roy. Soc. Arts*, vol. 59, July 7th, 14th, 21st, 28th, of 1911.

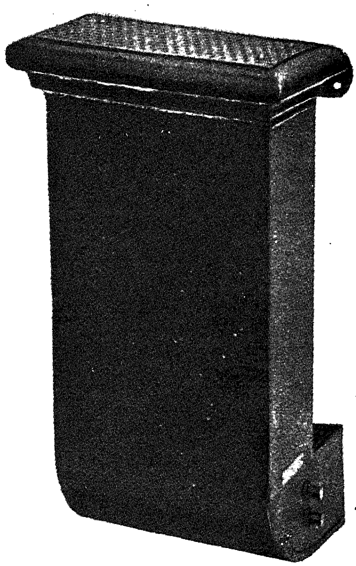
PLATE 5.



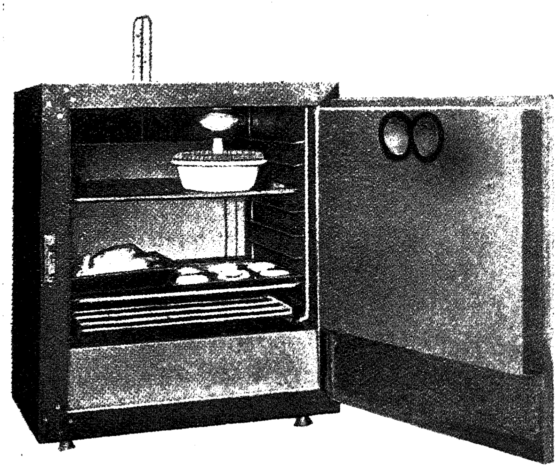
An Electric Convector. It contains coils of wire heated by an electric current, which in turn heat the air passing through it.



A Luminous or Lamp Radiator or Electric Fire (See page 209.)



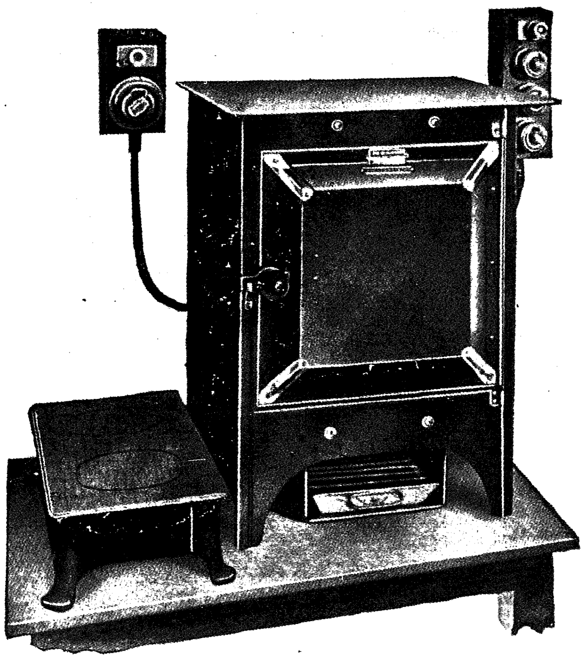
An Electric Tobin's Tube. It contains coils of wire heated by an electric current, which in turn heat the air passing into the house from outside through the tube. (See page 210.)



Bertram Thomas Electric Oven. Within the double walls of the oven are coils of wire heated by the electric current, which in turn heat the air in the interior. (See page 211.)

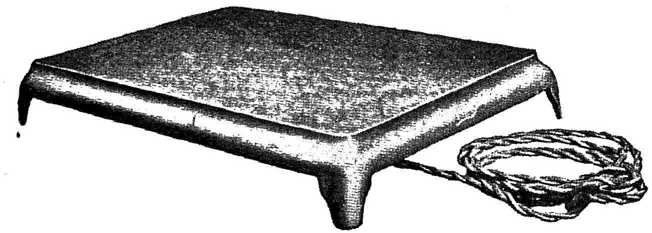
[*To face page* 214

PLATE 6.

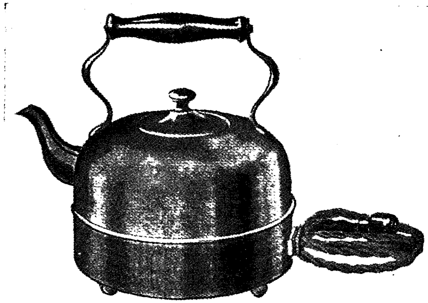


[*By permission of Berry's Electric, Ltd.*

An Electric Oven. It has in the interior one or more electrically heated plates which raise the temperature to cooking point when the switch is turned on. It requires no chimney, as there are no fumes or waste gases, and is clean, effective, and convenient.



An Electric Hot Plate. In the interior are coils of wire heated by the current.



An Electric Kettle. The kettle has a double bottom, and in this are fixed certain coils of wire heated by an electric current, which in turn heat the water in the kettle. The plug at the end of the wire can be put into any lamp-holder of the right voltage. (See page 211.)

[*To face page* 215.

by many electric supply corporations at 0·5*d.* per B.T.U. for heating purposes. At present it is not supplied for less than 1*d.*, or even 2*d.*

Accordingly, we may say that at present the heating of the above-mentioned quantity of water would cost at least 6*d.* by electric heating.

The author made in 1911 a large number of experiments on the relative efficiency of electric kettles and saucepans in regard to water heating in comparison with the same operations conducted over a gas ring.

We know from the calculations above given the theoretical amount of energy required to heat a given weight of water through a certain range of temperature. It is found that, in practice, it requires somewhat more energy, and the efficiency of the apparatus is the ratio of the theoretical to the actual amount of energy taken.

Thus, using a certain kind of electric kettle having the heating wires in a double bottom, it was found that to bring 2 pints of water from 60° F. just to the boiling point for making tea required 130 watt-hours of electric energy. The theoretical amount is 110 watt-hours. Hence the efficiency of that kettle was $11/13 = 84$ per cent.

Similarly, a saucepan of the same make required 105 watt-hours to raise $1\frac{3}{4}$ pints of water from 60°—212° F. The efficiency is, therefore, 91 per cent.

It is evident, therefore, that a good electric kettle has an efficiency comparable with that of a good dynamo, considered as an energy-transforming device.

The efficiency of electric water-boiling apparatus on the hot plate system is not nearly so high as that on the self-contained heater system. In the former it is important that the kettle should have a perfectly flat and bright bottom surface, so as to make good contact with the iron plate, or else there is a very slow transference of heat from the plate to the water.

In the case of a large self-contained immersion heater in an apparatus called a Therol, for heating water, the author found an efficiency of 92 per cent.

It is interesting to compare the performance of electric kettles with those of ordinary kettles heated over a gas ring. The value of coal gas for heating purposes is estimated by the number of British thermal units

produced by the combustion of 1 cubic foot of the gas. For town supplies of gas this is, roughly, 550 B.Th.U. per cubic foot.

Since 1 B.Th.U. = 0·294 watt-hour, we may say that ordinary coal gas has a calorific equivalent, as it is termed, equal about to 162 watt-hours per cubic foot, or 162 Board of Trade units per 1,000 cubic feet. This value varies somewhat in different places.

The author found that for an ordinary gas ring as used in most kitchens, and using an enamelled iron kettle, it required 0·9 cubic feet of gas to raise 1 pint of water to the boil. This means that 146 watt-hours of energy was supplied to produce the heat theoretically equivalent to 55 watt-hours. The efficiency, therefore, was only 34 per cent. For each kettle there is, however, a certain most economical size of gas ring and rate of supply of gas. Using for the above kettle a smaller gas ring it burnt only 0·67 cubic feet of gas, and the efficiency rose to 53 per cent. Nothing is gained by forcing the supply of gas or turning on more gas, since the efficiency then falls.

It is wasteful to turn on gas to the point that the flame curls round the bottom of the kettle.

Generally speaking, we cannot obtain so high an efficiency by gas as by electricity, but the question in the ultimate issue is one of cost, and at present prices of gas and electric energy the cost is slightly in favour of gas, but the indirect advantages enormously in favour of electricity as a heating agency.

When we have electric energy produced on a very large scale and delivered to user from power stations specially designed with the object of the reduction of cost, we shall be able to reduce the cost per unit to the user to a point which will make the advantages, direct and indirect, of electric heating for domestic purposes preponderate greatly over the methods depending on the consumption of coal or gas.

Having regard to all the disadvantages and discomforts of the use of raw coal in houses for heating, we look forward confidently to the time when it will be prohibited and the choice will lie between the use of a gas with high calorific power, prepared exclusively for heating, and the employment of electric energy with all its great inducements in respect of safety and cleanliness.

We must not conclude this chapter without a few words on a technical application of electric heating of great importance, viz., electric welding. It is well known that if two pieces of iron are made bright-red hot and then put in contact and hammered, the pieces weld together. Several other metals will also weld, provided the surfaces in contact are made clean and free from oxide or rust. If we put in contact the ends of two cold iron rods and pass a powerful alternating current across the junction, very great heat is produced, causing the ends to become white hot. This is because the imperfect contact has a high resistance and, therefore, by Joule's law heat is rapidly produced there.

If, then, the ends of the white-hot rods are pressed together they will weld and stick together. The same thing can be done with copper or aluminium or any metal which is not too fusible. It therefore occurred to Professor Elihu Thomson to make a machine called a welding transformer.

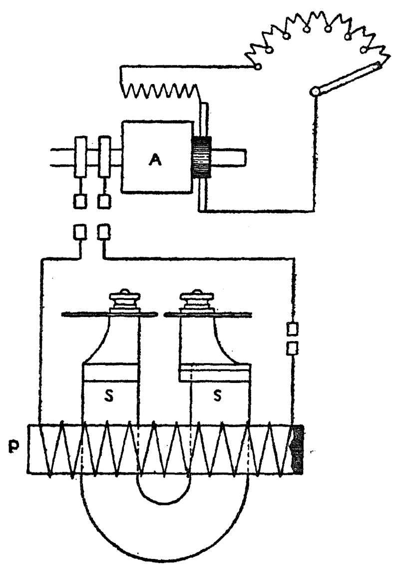


FIG. 12.—A Diagram illustrating the Construction of an Electric Welding Machine. A is an alternating current dynamo which supplies current to a primary coil of wire P wound on an iron core. This is embraced by a massive loop of copper S, and the rods to be welded form the ends of this loop. When the circuit is complete a very strong alternating current is produced in the circuit S. This heats the junction where the rods press together and welds them.

In this we have a ring or closed circuit of iron, generally of rectangular shape, on one side of which is wound a large number of turns of insulated wire. Through this wire is passed an alternating current of electricity. This magnetises the iron core, the magnetisation reversing in direction with every change in the direction of the current (see Fig. 12).

Round the iron core is wound a single turn of very thick copper cable, which terminates in two jaws of copper suitable for clamping in them bars of iron or other metal to be welded, so that their ends are in contact. These jaws can be made to approach each other by a screw

turned by a hand-wheel. If, then, we wish to weld together two bars of iron we clamp them in the jaws with their ends in close contact. We then switch on the primary alternating current into the long wire coil of the transformer, and this at once induces in the short, thick wire coil an enormous alternating current, which passes through the junction where the iron bars touch. It makes them at once white hot at the tips. A turn or two is then given to the screw to press the ends together and the current is switched off. In far less time than it takes to describe we have a complete solid weld of the two bars (see Plate 7). In this manner, by the employment of suitable welding machines the iron rails of railways or tram lines can be welded together. Also the links of chains can be welded, and a great variety of pieces of metallic construction work carried out on articles large and small. The rims or tyres of bicycle and perambulator wheels are quickly welded by such an appliance. (See Plate 7.)

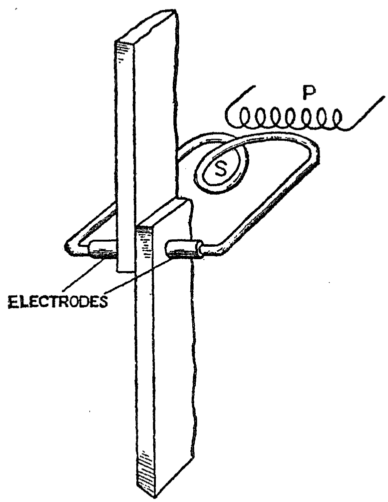
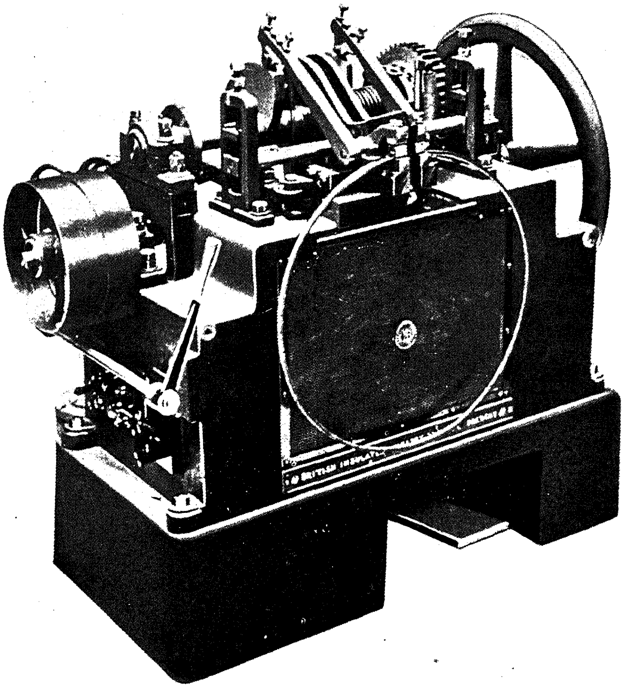


FIG. 13.—A Diagram to illustrate the Process called Spot Welding. P and S denote the primary and secondary circuits of a transformer. The powerful secondary current produced is passed through the junction of two iron plates and heats the spot, so that the plates are welded together by the intense heat produced at the joint.

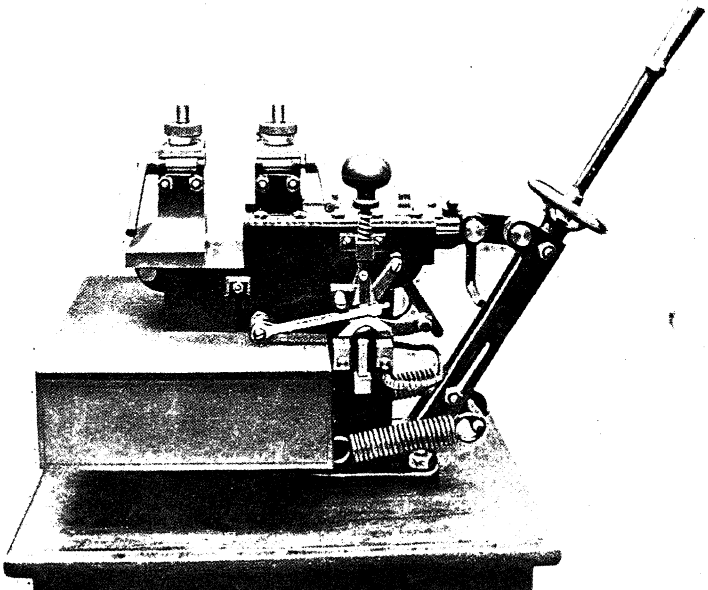
The above type of welding, by means of welding transformers, is generally called *butt*-welding. There are also other types of electric welding in extensive use, viz., *arc* welding and *spot* or resistance welding. The latter type has of late years been extensively developed in connection with ship construction. It consists in bringing into good contact by water or air pressure pumps overlapping portions of two plates or strips of iron, steel or other metal which are required to be joined, and then sending through the contact a very large alternating electric current, provided by means of a transformer, which raises the temperature of that spot to a welding heat, and then the pressure takes effect and welds the parts together. This process is then repeated from spot to spot until the whole

PLATE 7.



[*By permission of the British Insulated and Helsby Cables, Ltd.*

An Electric Welding Machine for Welding the Rims of Perambulator or Bicycle Wheels. It can weld 10—15 rims per minute, and takes 11 h.p. to work it.



[*By permission of the British Insulated and Helsby Cables, Ltd.*

An Electric Welding Machine for Welding Brass or Copper Bars. These are inserted in the clamps at the top, and the alternating current from the transformer sent through the junction. When the tips become incandescent, the lever (on the right) is pushed over and forces the hot ends together and so welds them. (See page 218.)

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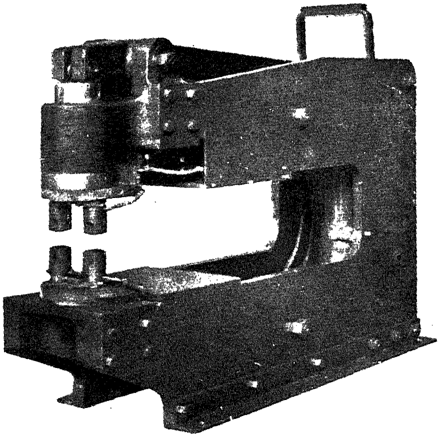
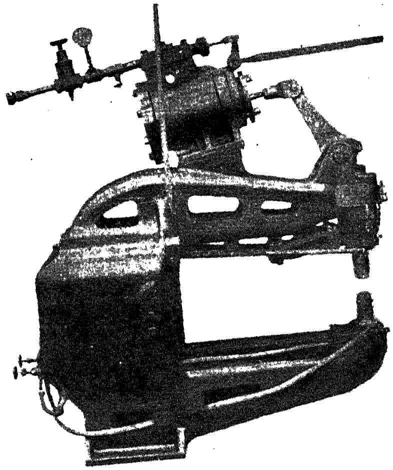
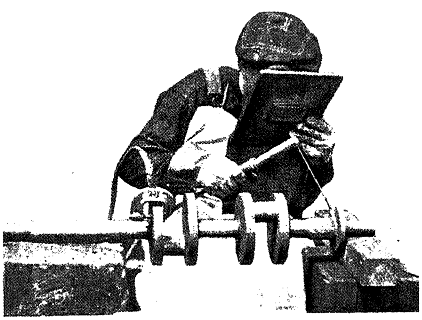
PLATE 8.



A Duplex Spot Welder.



A Portable Spot Welder.



Metal Arc Welding.

Carbon Arc Welding.

[*By permission of the American Institute of Electrical Engineers, and Mr. H. M. Hobart.*

The two upper diagrams give views of spot welding machines. The plates to be welded are overlapped and placed between the punches on the jaws. A strong electric current is then passed and intensely heats the spot, whilst at the same time by means of hydraulic pressure the plates are pressed together. The process is repeated from spot to spot until the plates are firmly welded together. The result is to produce a better joint than that obtained by riveting. Enormous secondary currents up to 70,000 amperes are sometimes employed. (See page 218.) The two lower diagrams illustrate arc welding. (See page 220.)

[*To face page* 219.

areas to be joined are welded. In the United States of America this process has been brought to great perfection, and a large variety of spot-welding transformers have been invented (see Plate 8). The process essentially consists, as the diagrams in Figs. 13 and 14 show, in making the plates to be welded form part of the secondary circuit of a large transformer, the current generated in it by the primary coil being sent

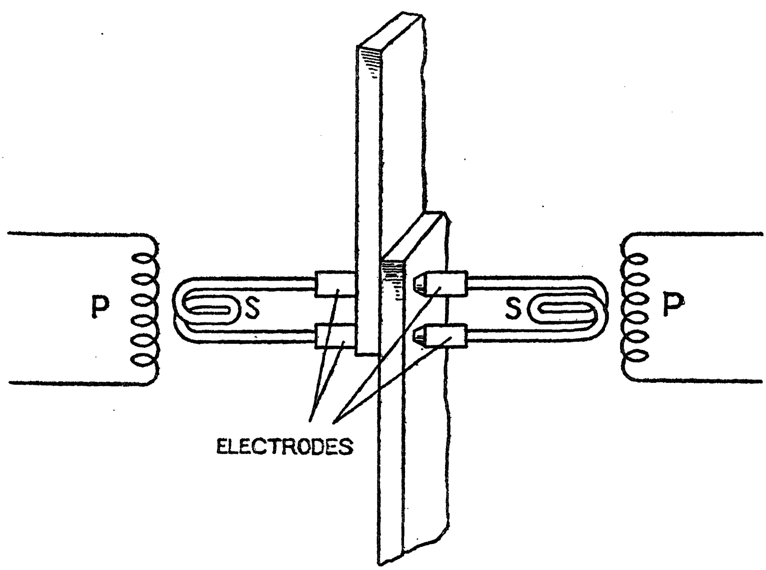


Fig. 14.—A Diagram to illustrate the Construction of a Double Spot Welder, in which two transformers P and S and two pair of electrodes are employed to produce sufficient heat at a junction of two overlapping iron plates to weld them together. This process replaces the old one of riveting.

through the parts which are being pressed together. These diagrams have been taken by kind permission of Mr. H. M. Hobart from a paper by him on the welding of mild steel read in New York, U.S.A., February 19th, 1919, at a Convention of the American Institute of Electrical Engineers.

In this manner iron ships have been entirely built up by welding the plates instead of riveting and caulking them. The other type of electric welding which has been brought into extensive use is that of *arc* welding. If we connect a metal plate or piece of metal work to one pole of a dynamo or alternator and to the other pole a metal, say, an iron rod or else a

carbon rod, we can create an electric arc between the plate and the rod by bringing them in contact and then separating them slightly. In this arc a metal wire can be fused and fed forward, and by this means it is possible to supply molten metal to certain points, to melt or soften parts of the work, to join together by semifusion two pieces of metal, or to patch and make good defects. The arc terminal is held and guided by a workman who also holds the filling wire or rod which supplies the necessary new metal when a carbon rod is used to form the arc (see Plate 8). His eyes are protected from injury by the use of dark spectacles or glass.

Some difficulties connected with the tendency of molten iron to oxidise can be avoided by employing metal electrodes covered with a coating of various materials, which acts as a flux and prevents the molten metal from being oxidised or combined with the oxygen of the air. These are called *covered electrodes*, and are made in various forms and with various coverings for various purposes.

This arc welding is a most useful method for executing certain repairs to boilers or furnaces due to cracks or worn places in plates, or for making good defects in castings (see Plate 8). When properly carried out with covered electrodes this electric arc welding can make joints between plates such that the strength is in every way equal to that of a solid plate.

It is necessary for the workman conducting the process to have his eyes and face protected from the intense heat and from the dangerous ultra-violet light emitted by the metallic arc. This is achieved by his wearing a special type of mask and spectacles.

Electric arc welding has been found to be of great value in the construction of oil tanks and containers for petrol, which are extremely difficult to make quite tight by ordinary riveting.

The advantages of electric welding are the great saving of time compared with that involved in marking off, punching or drilling holes and pressing up rivets; also, owing to the lesser overlap required for plate joining, there is an economy in metal.

A riveted joint for oil or water begins to leak badly long before the stresses are sufficient to break the joint, whereas a welded joint is tight up to its breaking point.

CHAPTER V

ELECTRIC SUPPLY STATIONS, STORAGE BATTERIES, RAILWAYS AND THE TRANSMISSION OF POWER, 1870–1920

THE improvements which numerous inventors had made in the dynamo between 1870 and 1880 and the practical solution of the problem of making an incandescent electric lamp suitable for domestic illumination arrived at by Edison and Swan towards the end of that decade suggested at once that electric current should be laid on to houses and buildings in a city for private electric lighting, just as water and gas is delivered. Edison and St. G. Lane Fox were amongst the first to devise plans for its practical accomplishment. They contemplated the erection of an electric station near the region to be supplied in which electric current was to be generated by groups of dynamos, and from which it was to be distributed by copper conductors laid under the ground.

Edison was the first to work out all the details of such public electric supply in a thoroughly practical manner, between 1878 and 1880; and, in fact, the invention of the high-resistance incandescent lamp was only one step in the realisation of his larger ideas.

He saw that for this to be possible the voltage or pressure of the electric supply must not be so high as to be dangerous, and, also, it must be possible for each lamp or motor to be turned on or off without affecting any other similar devices in use elsewhere. This implied that the voltage of supply must be somewhere about 100 volts, and that each electric lamp or motor must have its terminals connected to two supply wires between which the above constant pressure is maintained. It was necessary, therefore, to arrange all generating and all consuming devices "in parallel" between the supply mains, just like rungs of a ladder between the two side bars (see Fig. 1). (See also Fig. 5, p. 161, in Chapter III.)

By employing a number of dynamos arranged in parallel at the

generating station it became possible to add or remove individual units, so as to keep the generating plant nearly fully loaded at all times of the day, and thereby avoid the waste of running the machines at a fraction of their full load capacity.

Moreover, the failure of one dynamo would not then incapacitate entirely the generating station, as "all the eggs would not be in one basket." Edison, therefore, proceeded to invent the appliances for such

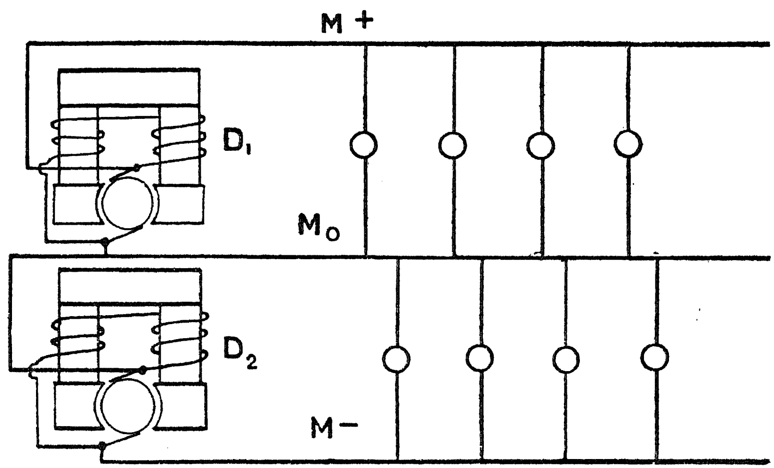


Fig. 1.—Shunt-wound Dynamos D_1 and D_2 supplying electric current at constant voltage or pressure to incandescent lamps (represented by the small circles) arranged "in parallel" between two supply mains M+ and M_0 or M— and M_0. Each lamp is supplied at the same electric pressure and can be switched on or off the circuit as required without affecting the light of other lamps. The above diagram shows a *three-wire* system of supply in which the lamps are divided into two groups arranged between three mains. (See also Fig. 5, Chapter III., p. 161.)

a "central station" system, in which electric energy was supplied by meter for lighting or power.

He selected as his standard voltage or pressure of supply 110 volts, and he designed constant-pressure shunt-wound dynamos with drum armatures for working in parallel. The general construction of these machines, with their long magnet legs, has been described in Chapter II.

In order to regulate the voltage of each machine, Edison provided a variable resistance, which was inserted in the field magnet circuit of

each machine, in the form of coils of wire, so that, by adding or subtracting resistance to or from the magnet shunt circuit, the magnetising current, and, therefore, the magnetic field of the dynamo, and hence the electromotive force (E.M.F.) in volts given at the brush terminals, was reduced or increased. In this manner an exact adjustment of the E.M.F. of the dynamo could be secured.

Edison had also recognised that for this parallel working each electric lamp must have as high a resistance as possible. The carbon filament lamp he invented in 1880 was the bamboo filament lamp, which gave a light of 16 c.p. for an expenditure in it of 64 watts electrical power, when supplied at 110 volts. Therefore, the current taken by each filament was $64/110 = 0{\cdot}6$ ampere nearly, and its resistance when incandescent was nearly 200 ohms.

As regards underground conductors, Edison considered that it would be necessary to lay them in iron pipes, like gas-pipes, each containing two insulated copper conductors, the whole system forming a double network of wires, the electric pressure or potential difference between the two networks being everywhere kept at 110 volts (see Fig. 2). To achieve this, Edison invented his "feeder" system of conductors.

At the generating station the various dynamos sent their currents into a pair of copper bars, called "bus bars." From these bus bars proceeded a number of pairs of other copper conductors, called feeders, to which no lamps were attached. The feeders were connected into the street distribution system or networks at various feeding points, which were generally placed at places in the network where the demand for current was greatest. From the street network pairs of supply wires led into the different houses supplied, and the current was passed into the house wiring through an electric meter. Every lamp was then supplied at the constant pressure, say, 110 volts, and could be turned on or off at pleasure without affecting the rest.

Edison also introduced the "safety fuse" or "cut out," which consisted in a piece of lead wire or strip inserted at certain places, which fused if the current became abnormally high and cut out the overloaded section of the circuits.

The conductors Edison used were rods of copper of semi-circular

section insulated from each other by spacing pieces and then placed in an iron pipe and melted asphalt or bitumen forced in to fill up the space. These tubes were made in 10 or 15 feet lengths and the conductors jointed together in iron joint boxes which were then filled in with the bituminous compound (see Plate 1, upper diagram).

The dynamos Edison designed for central station work were made with multiple leg electromagnets ending in massive iron pole pieces in the

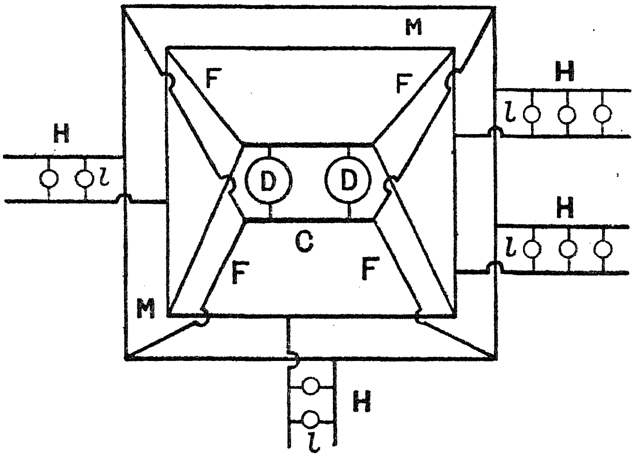
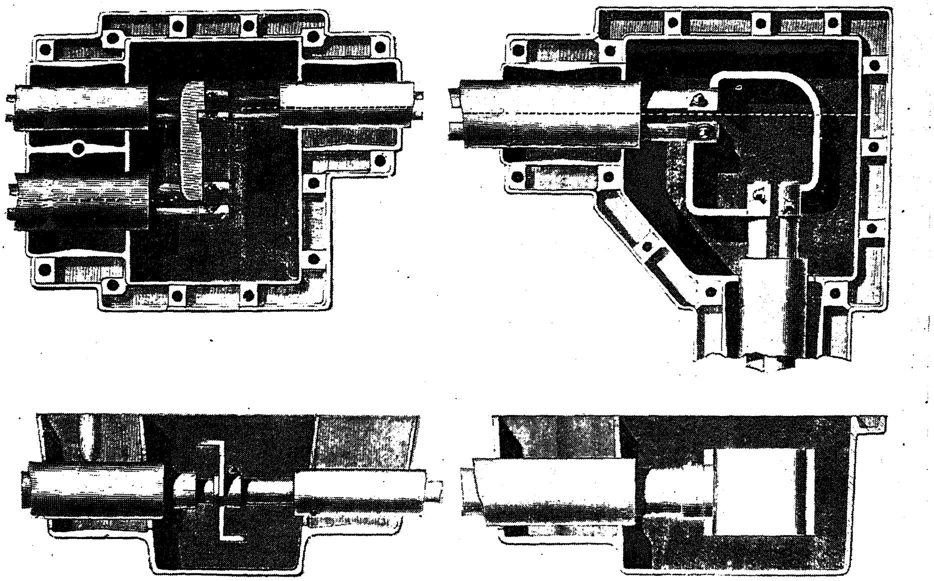


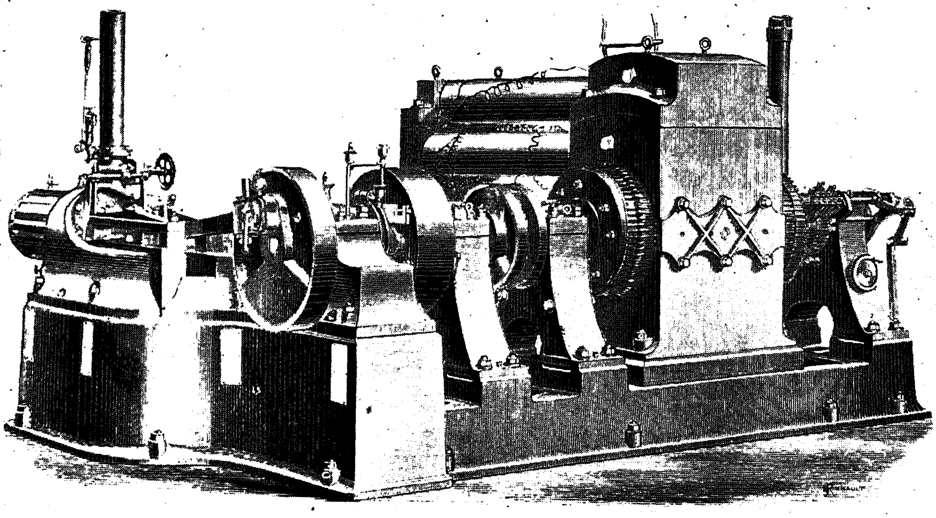
Fig. 2.—Edison's Feeder System of Low Pressure Electric Supply. D D are shunt-wound dynamos at the generating station C feeding electric current at constant voltage or pressure into a pair of copper conductors called "bus bars." From these proceed other pairs of conductors called feeders F, F, which supply current to distributing mains M to which the house circuits H are connected which feed the lamps *l* at constant pressure.

interspace of which revolved a drum-wound armature. This armature was direct-coupled to a 150 h.p. Porter-Allen high-speed single cylinder steam engine. The dynamos could furnish about 800 or 900 amperes at 110 volts, sufficient to maintain about 1,500 Edison 16 c.p. lamps in action. At the date when these machines were built they excited great wonder from their size, which was beyond anything then constructed. They became known as the "Jumbo" dynamos, the name being taken from that of a very large tame elephant then at the Zoological Gardens, which was a great favourite with children from the number he could carry on his back at once.

PLATE 1.



Edison Electric Tubing containing two Copper Conductors for laying under streets for the public distribution of electric current, showing also the plan and section of straight-run and angle-joint boxes.



The Edison 1,500-light 110-volt Steam Dynamo called the "Jumbo." Installed in 1882 at Holborn Viaduct Station, London, at Milan, in Italy, and at Pearl Street Station, New York City, U.S.A., the first Edison Public Electric Supply Stations. The dynamo armature was coupled direct to the shaft of a 150 h.p. Porter-Allen engine. Note the multiple legs of the field electromagnets.

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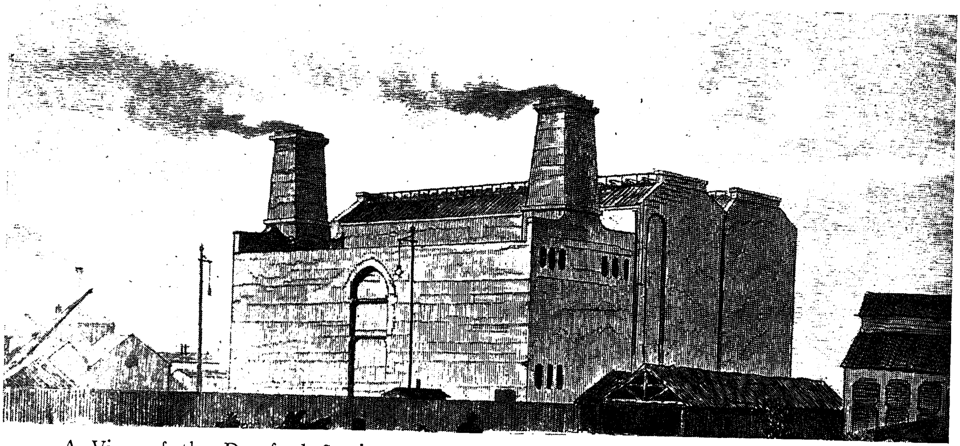
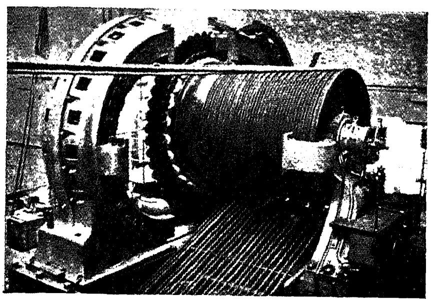
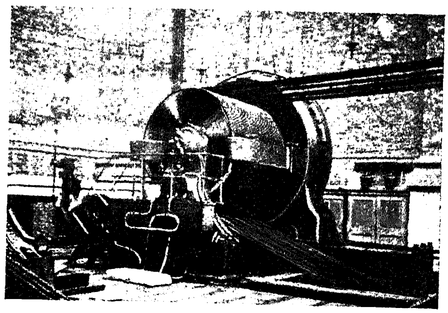
PLATE 2.

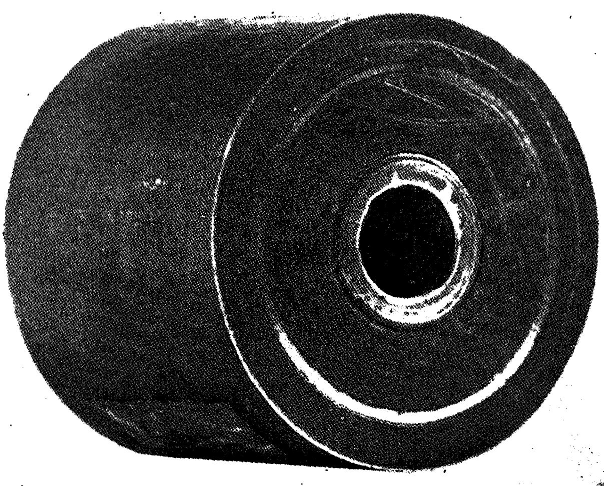


A View of the Deptford Station of the London Electric Supply Corporation, Ltd. Ferranti system.





Ferranti Rope-driven Alternators at Deptford Station.



Section of a sample of Ferranti Electric Supply Main consisting of two concentric copper tubes separated by resined paper insulation. The outer diameter of the inner tube is 0·8 of an inch and the inner diameter of the outer tube 1·8 inches. The tubes are contained in an outer steel tube and made in 20-foot lengths.

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The first Jumbo steam dynamo was sent to Paris and exhibited there in 1881 (Plate 1). In the same year Mr. Edison's business representative, Mr. E. H. Johnson, came over to London with a staff of experts and prepared to establish a typical Edison supply station at 57, Holborn Viaduct. The basement of the building was equipped with two Babcock and Wilcox water-tube boilers and the second and third Jumbo dynamos were installed there to supply the adjacent offices and buildings with incandescent lighting in the months of January, 1882. The author was appointed electrical adviser of the Edison Electric Light Company early in 1882 through the kind influence of Mr. Arnold White, the then secretary of the Company.

Many difficulties had to be surmounted before a continuous supply of electric current could be given. Methods of armature insulation and construction were very imperfect at that date and failures at first were frequent, necessitating stoppage of supply.

A similar, but larger, supply station was meanwhile constructed under Edison's own superintendence in New York City, at Pearl Street. It was opened in September, 1882, with six of the large Jumbo machines as generators, and a lamp connection of 6,000 or 7,000 lamps was soon obtained.

Many practical difficulties had to be overcome before an uninterrupted supply could be given, and on many occasions it was necessary for Mr. Edison to take off his coat and practically instruct the workmen in the laying of street mains or the running of dynamos in parallel at the supply station. At first it was considered quite a feat if a dynamo could be kept going for a day or so without some failure necessitating a stop for repairs. It was only by slow degrees that success in the construction necessary in the case of supply station dynamos was obtained.

The author visited this New York station in September, 1884, and was allowed to make a full and detailed report on its construction and commercial position to the Edison and Swan United Electric Light Company of London. Even at that date the New York station had proved that electric supply could become a profitable industry. A similar Edison station was established at a little later date in Milan, operated with the same type of dynamo.

One of the difficulties which first presented itself was the limited distance or range of working which could be economically reached with supply at 110 volts and an incandescent lamp having a resistance of 150—200 ohms when working. The electric power expended in each lamp is proportional to the square of the voltage of supply and inversely as the resistance of the filament.

Hence if a certain number, say 1,000 lamps, are supplied at 110 volts at the end of an electric main, say 1,000 yards long, the total resistance of all the lamps in parallel will be $\frac{1}{1000}$ of that of one of them, or $\frac{1}{1000}$ of 110 times 110 divided by the watts taken by each lamp. The same total current which flows through the lamps flows also there and back through the supply mains. Hence, if we adjust the section of that main to such a size that 10 per cent. of the total power given to the lamps will be wasted as heat in the mains it will follow that the resistance of the supply main must be 10 per cent. of that of all the lamps in parallel. But the electric resistance of the main is proportional to its length and inversely as its cross section. It is therefore easy to see that for a given number of lamps each having a certain resistance and supplied at various voltages through mains of a given length, the section of the main will have to vary inversely as the square of the voltage to keep the percentage loss in the mains constant. This means that if we double the supply pressure we can make the section of the main, and therefore its cost, one-quarter as great. Also it follows that for a given section the distance at which we can supply for a given percentage loss in the mains increases as the square of the supply voltage. Hence if we double the supply voltage we can transmit four times the distance with the same percentage energy loss in the mains. Accordingly, there is every advantage in raising the supply voltage, but the difficulty is to do it without increasing the power taken by each lamp or its candle-power.

This problem was solved almost simultaneously by Dr. John Hopkinson and Mr. Edison in the invention of the *three-wire* system of supply.

In place of a pair of main conductors to which the terminals of the constant potential dynamos and those of all the lamp filaments were connected, three conductors are used and the total number of lamps is

divided as nearly as possible into two equal groups, and half of them are connected across between the positive and the middle main and half of them between the middle and negative main. The dynamos are joined two in series and connected in like manner (see Fig. 1, page 222). If the number of lamps on the two sides of the middle main were always exactly the same the middle main could be omitted. We should then be working the lamps two in series at double the voltage required for the two-wire supply. In accordance with what has been explained the section of each main need then be only one quarter of the section on the two-wire system for equal percentage waste of power in the mains. If, however, the number of lamps is not exactly equal, then a middle or intermediate wire must be provided, which carries back to the station a current equal to that required to supply the difference in the number of lamps on the two sides. Taking the middle main into account, this means that for equal proportional waste of energy in the mains on the two systems the total quantity of copper required for the three-wire system is only three-eighths of that required on the two-wire system, and hence there is a saving of $62\frac{1}{2}$ per cent. Otherwise we can show that for equal total weight of copper in the mains and equal percentage loss of power we can operate on the three-wave system at $33\frac{1}{3}$ per cent. greater distance compared with the two-wire system.

As the middle wire has only to carry a current equal to the difference between those taken by the two groups of lamps on both sides it need not be of equal section, and is generally a little smaller. Hence in practice the three-wire system effects a greater economy in copper as compared with the two-wire than above stated. Instead of employing two dynamos in series it was found better to construct the main dynamos to supply at over-all pressure between the two outer mains and to place a pair of small dynamos in series to supply the difference in current between the two sides.

This three-wire system of direct-current supply at once became the standard low-pressure system, and at the present time is everywhere adopted. At a later date when it had been found possible to manufacture carbon filament lamps of 16 c.p., having a resistance of 700 or 800 ohms when hot, it was possible to increase still more the supply

voltage and effect further economy in copper in the distribution mains and feeders.

At the present time (1921) the standard low-pressure system of direct-current supply is a three-wire system having a pressure of 220 volts between positive or negative outer main and the middle conductor. The generating dynamos are built to supply current at about 460 volts and connected between the two outer mains, which, allowing for a certain drop in pressure in the feeders, are kept at 440 volts difference of potential.

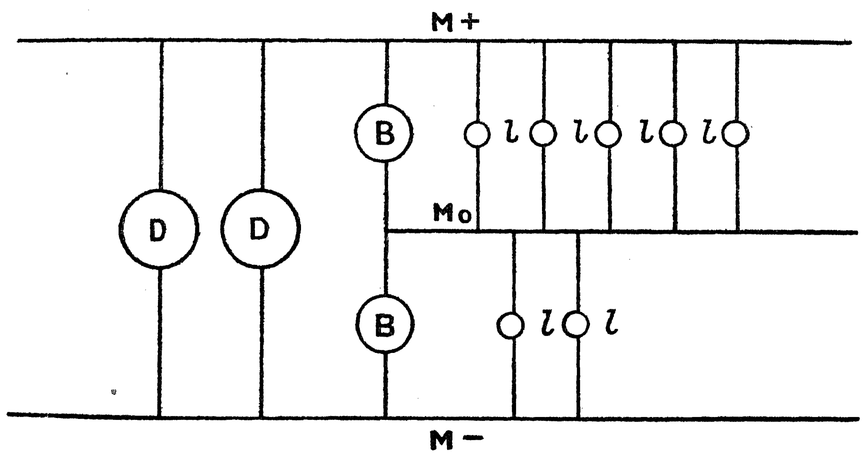


Fig. 3.—Diagram illustrating the Edison-Hopkinson System of Three-wire Low Pressure Electric Supply. D, D are the dynamos at the supply station furnishing current to the outer conductors M + and M — of a three-wire system. *l*, *l* are the lamps arranged in parallel-series, B, B are the small dynamos which supply the current for the difference in the lighting load on the two circuits.

The lamps are divided as nearly as possible between the two sides of the system, but to supply the differential current due to want of exact equality in the demand between the two sides, two balancing dynamos are connected in series and across the mains, as shown in Fig. 3. In some cases storage batteries are employed, made as described later in this chapter, and two such batteries are connected across the two sides of the three-wire bus bars. If the lamp voltage is 220 volts, then each battery consists of 110 cells. To charge these batteries an additional electromotive force is necessary, which is supplied by a small dynamo called a "booster."

This dynamo is generally driven by coupling its shaft to that of one of the balancing dynamos used as a motor (see Fig. 3, and Plate 10, page 256).

In Fig. 3, D, D are the main generator dynamos giving an E.M.F. of 460 volts or so. B, B are the balancing dynamo-motors and *l*, *l* are the lamps arranged between the three mains in parallel.

The three-wire bus bars are + M, M_0, − M, and the distributing mains are also triple conductors, and from them pairs of service conductors are taken to supply the lamps in parallel across the + and middle or − and middle service mains.

As long as the balance is kept between the two sides by the lamps in use being exactly equal, neither the balancers, boosters, nor batteries contribute any current. The lamp currents are supplied by the main dynamos. If, however, more lamps are in use on one side than the other, then one of the balancers acts as a dynamo and is driven by the other acting as a motor, and the dynamo booster supplies the difference in the current taken by the two groups of lamps. When the balance is exact both balancer dynamos B, B take current from the main dynamos D, D, and run as motor. They drive the boosters and charge the batteries. When the balance is not exact then one balancer acts as a dynamo and supplies the out-of-balance current required.

A very little experience in the supply of electric energy to the public from supply stations served to direct the attention of electrical engineers to the economics of the subject. When a large number of users have electric lamps, furnished with current from supply stations by meter, the customer naturally switches on his lamps only as required for light. If the customers are all of one class, say, private residences, their demands for current come on at much the same time. If, then, the total electric current flowing out from the station is measured at short intervals during the twenty-four hours of the day and night, and vertical lines drawn on a diagram to denote to scale this current at the various hours, the tops of these lines define a curve called a *load diagram* (see Fig. 4).

In a residential district this load diagram in the winter is a curve having two humps on it, a small one and a large one. The first occurs between the hours of 6 and 8 a.m. and is due to demand for light in the early morning and about breakfast time. The second occurs between 4 and

8 p.m., when most people are using their maximum number of lamps. In between these hours the demand diminishes. It is very seldom that all the lamps installed in a private house are in use at once, but there is a certain *maximum demand* for each class of user. We have also to distinguish between the load diagram for each individual user and the load diagram for the supply station as a whole, which is a kind of average.

If we consider the station diagram, it is evident that the total output

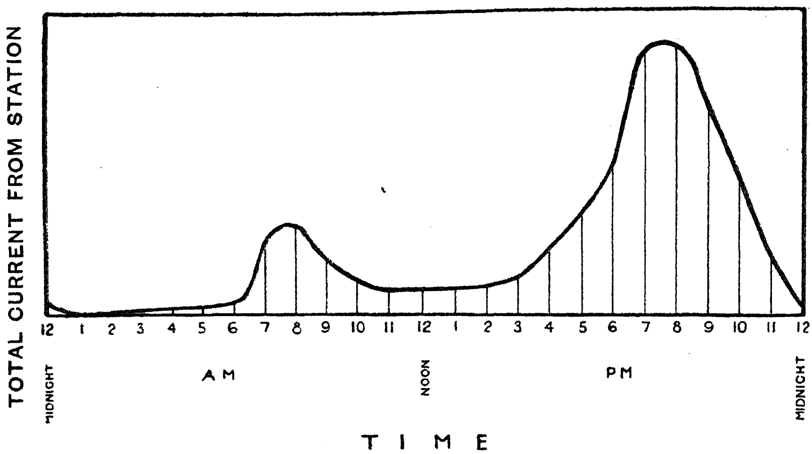


FIG. 4.—A Typical Winter "Load Diagram" of an Electric Supply Station. Vertical heights or ordinates of the curve represent to some scale the electric current output of the station at the hours of the day or night as marked on the base line. The total area included by the firm black line curve gives us the "ampere-hours" sent out from the station per day. The maximum height of the curve gives us the "peak" or greatest load of the day.

of the station in ampere-hours can be obtained by taking the area included by the load curve and the base line and terminal ordinates or vertical lines. Suppose then that we draw a horizontal line through the extreme top of the highest peak on the load diagram and calculate the area of the rectangle so obtained. The ratio of the area included by the load curve to the area included by the above rectangle is the ratio between the actual number of units of electric energy sent out by the station to the number which would be sent out if the demand were at all moments the same as the maximum. This is called the *load factor* of the station. It seldom

exceeds 10 or 12 per cent. in a residential district, but in a district full of hotels, restaurants and offices with basement rooms, where light is required in the day time, it may rise to a much higher value. It is a number of great importance in connection with the financial aspect of electric supply. For it is evident that in laying out a station sufficient engine, boiler and dynamo power must be put in to meet the maximum possible demand at the "peak hours" in time of greatest load. If, however, the load factor is low, then the greater part of this machinery will be idle most of the time. The annual interest on the capital outlay has to be met whether the plant is in use or not. But the plant is only earning money when it is being used to supply current.

There is another phrase, the meaning of which must be explained, and this is the *diversity factor*.

We have just explained that each consumer makes a certain maximum demand on the supply station at a certain hour. This hour may not be the same for all classes of customers. One class, say private houses, may takes its maximum power at 8 p.m. in the evening, whereas a theatre might take its maximum power about 10 p.m. or later, and a dark workshop in the day time. There is, however, a certain maximum for the whole station and the diversity factor is obtained by dividing the sum of all the consumers' maxima by the maximum for the whole station. Thus, for instance, if there are 100 consumers, each of whom takes 10 kilowatts as a maximum, the sum of all is 1,000 kilowatts. The maximum output of the station might be only 500 kilowatts, owing to the fact that the consumers do not all take their maximum at the same time. In this case the diversity factor would be 2. It is obvious that the higher the diversity factor and the load factor the better for the station as a commercial concern.

Space will not allow of a full discussion of the question of the best mode of charging for electric supply. It has long been recognised that a flat rate or mere charge per unit of electric energy supplied without regard to the consumers' maximum, or possible maximum, demand or to his individual load factor is unscientific, and it has been extensively abandoned.

We may merely observe that it is a general custom to charge much less

for units used for motors or for heating than for lighting, in order to encourage the use of motors and electric heating to improve the station load factor as a whole.

One of the arguments used in support of the three-wire direct current system of supply is that it is easy to obtain small motors suitable for working domestic machinery, fans, sewing machines, and the like, and so help the load factor.

When central station electric lighting by direct current was first established it was found that there were many towns and places where the demand was so scattered that it did not pay to put down the heavy feeders and distribution mains required on the D.C. system, the economical radius of supply of this being only about 1½ miles. Attention, therefore, became soon directed to the possibilities of alternating current supply.

This was assisted by the invention of new types of alternator and transformer, such as those of Ferranti, Mordey, and Parker, which have been already described in Chapter II.

Hence the distribution of electric energy at high pressure and its transformation by alternate current transformers to a low pressure began to be carefully considered.

This proposal was not then altogether new, for Paul Jablochkov had patented in 1877 (see British Patent No. 1996 of 1877) the idea of working his electric candles, which have been described in Chapter III., by supplying each candle with alternating current from the secondary circuit of an induction coil, the primary circuits of all the induction coils being joined in series and traversed by a high pressure alternating current.

It has already been explained in Chapter II. that Gaulard and Gibbs revived this project in 1882, and suggested the use of transformers in series for operating incandescent lamps. The reason why such a plan is not practicable has also been given. After the exhibition of Zipernowsky's transformers at the Inventions Exhibition in 1885, Mr. S. Z. de Ferranti, who had already invented his alternator, took out a patent (British Patent 15141 of 1885) for a type of transformer intended to be worked with the primaries of a number of transformers in parallel and groups of independent incandescent electric lamps placed in parallel

on the secondary circuit of each transformer. The primary circuits were supplied with electric current at high voltage, viz., about 2,500, and the transformers reduced this to about 100 volts for running the ordinary glow lamp.

This system had the great advantage that the electric energy was conveyed at high voltage and therefore by a small electric current requiring only thin and therefore relatively cheap electric conductors to convey it. Thus, for instance, if we had to light 1,000 of the carbon filament 16 c.p. glow lamps of that day, taking, therefore, 64,000 watts, or 64 kilowatts of power, we should only have to employ an electric current of about 25—30 amperes to effect this at a pressure of 2,500 volts. If we required to do it at a pressure of 200 volts we should have to transmit more than 300 amperes, or at least ten times as much current, requiring conductors at least ten times the section and more than ten times the cost.

Hence the transformer system offered the means of giving an electric supply service by means of high-pressure alternating currents conveyed by relatively small-section conductors, with transformers for the reduction of that pressure, in those cases in which the consumers were at considerable distances from the supply station. At first the custom was to give each consumer a transformer on his premises, and it therefore became known as the house-to-house system of supply. The distributing mains conveyed only small currents at a very high voltage.

The advantage of this in the case of country towns with consumers in houses far apart was found to be great. In some cases overhead conductors on telegraph posts were allowed for conveying the primary currents, and this rendered electric lighting from supply stations possible in country places where it would have been commercially impossible by low-pressure direct-current service with underground mains.

Before this time, however, the British Legislature had dealt a blow to public electric lighting service by their ill-advised Electric Lighting Act of 1882. As already mentioned, the Government, in 1870, bought the electric telegraph companies' plant and business for ten million sterling. Telegraphy in the hands of the General Post Office had, however, not proved to be a profit-making extension of its functions, but an addition to the burdens of the taxpayer. Moreover, the telephone had come in as a

rival, and although the Post Office had obtained a legal decision enabling it to tax the profits of the Telephone Company it was not content with this "unearned increment" but embarked on a policy of interference and control intended to prevent what was called "the upgrowth of another monopoly," but which has only resulted in a further loss to the community. The same erroneous ideas prompted the Electric Lighting legislation of 1882.*

Assuming that the duty of the Legislature should be to prevent or control the growth of any new independent public service analogous to that of gas or water supply, the Act of 1882, ironically termed an Act for "facilitating" electric lighting, provided that electric supply could only be undertaken by the authority of Provisional Orders issued by the Board of Trade, and that a local authority or municipality should have the power to purchase compulsorily any electric supply undertaking at the end of twenty-one years at the then value of its plant and works, without regard to goodwill or present or future profits.

On this basis, however, investors were not prepared "to pull the chestnuts out of the fire," and, therefore, for six years public electric supply in Great Britain remained in a moribund condition. When the author visited the United States in 1884 and explained to Mr. Edison the nature of the legislative shackles that had been applied to the business of electric supply in Great Britain, that distinguished inventor exclaimed, "Why, they've throttled it!" Meanwhile, in the United States, where no such interference had taken place, the industry advanced by leaps and bounds. Then began an agitation in Great Britain for an Amendment Act. In 1888, Lord Thurlow, speaking in the House of Lords on a Bill for this purpose, remarked that as a consequence of the 1882 Act not one of the sixty-four Provisional Orders for electric lighting granted by the Board of Trade had been put into operation in Great Britain, yet at that time there were 120 electric lighting stations in the United States paying dividends from 6 to 14 per cent. There were scores of stations in Germany and in Italy doing a large and profitable business.

* The manner in which British legislative action retarded the development of electric telephony, electric lighting, and electric traction in Great Britain, and the loss due to "nationalisation" of these services, was discussed by the author in an article written for *The Nineteenth Century and After* for February, 1901, entitled "Official Obstruction to Electric Progress."

The Amendment Act was passed and increased the purchase period to forty-two years. Investors could then obtain a fair chance for a return on their invested capital, and from that time the electric supply industry in Great Britain began to advance.

The alternating current transformer system of supply began to be put in operation first in London in a district round about the Grosvenor Gallery, Bond Street, about 1885, employing transformers in parallel on the house-to-house system as designed by Mr. Ferranti. One objection which had been urged against the alternating current supply in 1883 was that the alternators could not be worked in parallel. Mr. Wilde had proved in 1868 that it was possible, and Dr. John Hopkinson, in a paper read to the Society of Telegraph Engineers in 1884, gave a mathematical demonstration that it could certainly be done. This prediction was verified by Professor W. G. Adams in 1884, using two De Meritens alternators at the South Foreland Lighthouse, and in 1889, Mr. W. M. Mordey described to the Institution of Electrical Engineers remarkable experiments made with alternators of his own design, and discussed fully the conditions under which such alternators could be worked in parallel, like direct current machines. From and after that date great progress was made in the establishment of alternating current transformer stations. The Electric Lighting Amendment Act of 1888 and the holding, in April, 1889, of a Board of Trade Inquiry under Major Marindin, on the various Provisional Orders for the electric lighting supply of London, which up to that date had been shockingly behind New York and other large United States cities, paved the way for some important schemes.

Mr. Ferranti, who was in advance of his age in large ideas, had realised that the electric supply stations for a city like London must be situated at a point outside the area to be supplied where facilities for delivery of coal by water and water for condensation could be obtained. He accordingly enlisted the support of capitalists for a scheme for a large alternating-current station to be established at Deptford, on the Thames riverside, to supply at 10,000 volts pressure to transformers placed in the London area, which would reduce the pressure to that convenient for working incandescent lamps.

He also considered that large unit alternators were more economical

than a number of smaller size driven in parallel. Hence he designed for Deptford some large alternators of 1,500 h.p., direct driven by Corliss engines (see Plates 2 and 3). For the transmission of the current to the London transformer stations Mr. Ferranti designed a form of main consisting of two concentric copper tubes insulated from each other and from a steel enclosing tube by means of Manilla paper impregnated with certain resins and oils.

These tubes were made in lengths and jointed together by a copper plug and sleeve (see Plate 2, page 225, lowest diagram). The total distance from Deptford to the London transformer stations was about seven miles, and four such cables were at first laid.

The frequency of the electric alternations selected was eighty-three per second, and the high pressure was reduced in London by two steps, from 10,000 to 2,500 and from 2,500 to 100.*

These long concentric mains formed, as in the case of submarine cables, veritable Leyden jars or condensers, and had each an electrical capacity of about $\frac{1}{3}$ microfarad per mile. As soon as the Deptford station began to be worked, peculiar effects, new to electrical engineers, were observed, due to the capacity of these mains. It was found, for instance, that if the alternators had their fields excited so as to give 10,000 volts at the terminals of the alternator, then, when the long concentric mains were connected with no lamp load placed on them at the London end, there was a considerable rise in voltage at the alternator terminals. Also, a large current was found to flow into the mains at the Deptford end when no current was being taken out at the London end. These effects became known as capacity effects. The rise in potential on switching on the concentric mains was due to electric resonance, a phenomenon exactly similar to the increase in loudness of the sound of a tuning fork when held near to a hollow vessel the air in which has exactly the same natural frequency of vibration as the tuning fork.

At that time the author became connected as scientific adviser with the London Electric Supply Corporation, a public company formed to carry out Mr. Ferranti's projects.

* A description of the Deptford station as it was in 1902 will be found in the author's book *The Alternate Current Transformer*, Vol. II., p. 322.

The author investigated very carefully the capacity effects of these Ferranti mains, and described the experiments to the Institution of Electrical Engineers in a paper read in 1891, entitled "Some Effects of Alternating Current Flow in Circuits having Capacity and Self-Induction."

Another great difficulty soon presented itself. It was found that when these long concentric mains were suddenly switched on to the alternator or disconnected, a failure of insulation often occurred between the outer copper tube and the enclosing steel tube.

These effects were due to the fact that electric currents flowing in circuits possess kinetic energy to an extent which depends on the form of the circuit and on the current strength.

We know that we cannot start a heavy mass, such as a motor car, into quick motion instantly. Nor can we stop it suddenly when it is moving rapidly. We call the quality in virtue of which a moving body possesses energy its *mass*. The same thing is true of an electric current in a circuit. We cannot create it or stop it quickly without in some way dissipating or using up the stored energy. If we do break suddenly a circuit in which a strong current is flowing under high electromotive force, some mischief is bound to happen.

We call that quality of an electric circuit in virtue of which a current flowing in it has energy its *inductance*.

Thus it soon became clear to electrical engineers that there were great risks in suddenly switching in or switching out long electric mains, having capacity and inductance, from high-pressure alternators.

The phenomena of alternating currents began, therefore, to attract much attention, and were studied and expounded by Mr. Blakesley, Dr. J. Hopkinson, Dr. Kapp, Mr. Swinburne, Mr. C. P. Steinmetz, the Author and many others, in books and papers published between 1882 and 1892.

The practical remedy for the above difficulties was then soon found. It was manifest that in a large system of conductors for electric supply it is essential that no sudden changes should be made anywhere in capacity or inductance of the circuits or in current, but the currents must be changed slowly.

An arrangement was designed by Mr. Partridge, the Electric Supply

Corporation's engineer, for switching in or out the high tension mains, so that the current in all cases was changed in strength gradually, and not suddenly. This switching gear overcame all the difficulties above mentioned.

Another matter of importance which claimed attention at that time was the energy losses of the transformers in use. Reference has been made in Chapter II. to the prolonged experiments conducted by the author on this subject. The study given to the alternate current transformer and the necessity for improving it led to the invention and preparation of special types of mild steel for use in making transformer cores distinguished by extremely low energy loss under alternating magnetisation. This and the invention of improved types of transformer, such as the Berry Transformer, have given to this appliance a remarkably high efficiency and durability in working.

We have already explained in Chapter II. the nature of two- and three-phase alternating currents.

In the year 1891 there was an Electrical Exhibition at Frankfort-on-the-Main, in Germany, and an important demonstration was given of the electrical transmission of power by means of three-phase alternating currents. At this exhibition, for the first time, electrical engineers had an opportunity of seeing three-phase alternators driving asynchronous or rotating field motors made as described in Chapter II.

Most interesting of all was the Lauffen to Frankfort transmission of power by three-phase currents. Lauffen is a small town on the Neckar, 110 miles from Frankfort, and there is there a small fall of water, which is utilised by turbines to produce power. Some 300 h.p. was taken up to drive two three-phase alternators made by the Oerlikon Company in Switzerland. These machines generated three currents of 1,400 amperes at 55 volts and a frequency of 40 periods per second. This voltage was raised by transformers to 8,500 volts. The transmission line consisted of three copper wires, each 4 millimetres in diameter, carried on porcelain insulators on 3,000 telegraph posts stretching over the 110 miles. At the Frankfort end the voltage was again reduced by transformers to 65 volts, and utilised for lighting incandescent lamps and driving motors.

Tests of the plant carried out by a commission showed that 74 per

cent. of the energy given by the turbines at Lauffen to the alternator was received electrically at Frankfort. This experiment excited very great interest and surprise, as it demonstrated the commercial practicability of transmitting water power for long distances by high pressure three-phase currents. In particular it gave an impulse to a far vaster scheme of transmission of power from the Falls of Niagara, one of the greatest of all the electrical enterprises of the nineteenth century.

This last project began to be considered in or about 1892, and the question was debated whether two- or three-phase currents should be employed. Space does not permit of the statement of the case for each type, suffice it to say that many of the electrical engineers in the United States and Great Britain were asked for their opinion, amongst whom was the author, who advised the selection of two-phase, and this was ultimately adopted.

A type of two-phase alternator was decided upon after most careful consideration for the Niagara Power Station. The armature, on which were wound the two circuits for the two-phase currents, had the form of a cylindrical ring, and the field magnet was a dome-shaped cover of steel with inward-pointing magnetic poles on the bottom inside part (see Plate 4). This particular form was designed by Professor George Forbes to secure that centrifugal force should keep the field exciting coils on the poles and not fling them off. This umbrella-shaped magnet is the revolving portion of the alternator. In the first power station, constructed before 1899, this revolving field magnet is carried on the top of a steel shaft about 150 feet in length, connected at the bottom to the turbine water motor.

Enormous constructive work was necessary to utilise the water power of Niagara. A portion of the water on the upper river enters a canal, from which it falls down steel tubes, called penstocks, to the turbines at the bottom. From them it drains away through a tunnel to the lower rapids below the Falls. Above the turbine pits is the power house, which contains a dozen or more of the two-phase alternators, each of 5,000 h.p., which generate at a pressure of 5,000 volts (Plates 4 and 5, pages 241 and 242). This voltage is raised to 11,000 for transmission to the city of Buffalo, fifteen miles distant, and the Cataract Company, which own the power

station, supply thousands of horse-power to adjacent works for the manufacture of carborundum, aluminium, calcium carbide, alkali and other electric products, made as described in Chapter IV. In addition they furnish current for lighting, traction and heating to numerous towns and cities round. Altogether about 800,000 h.p. is now tapped from the Falls.

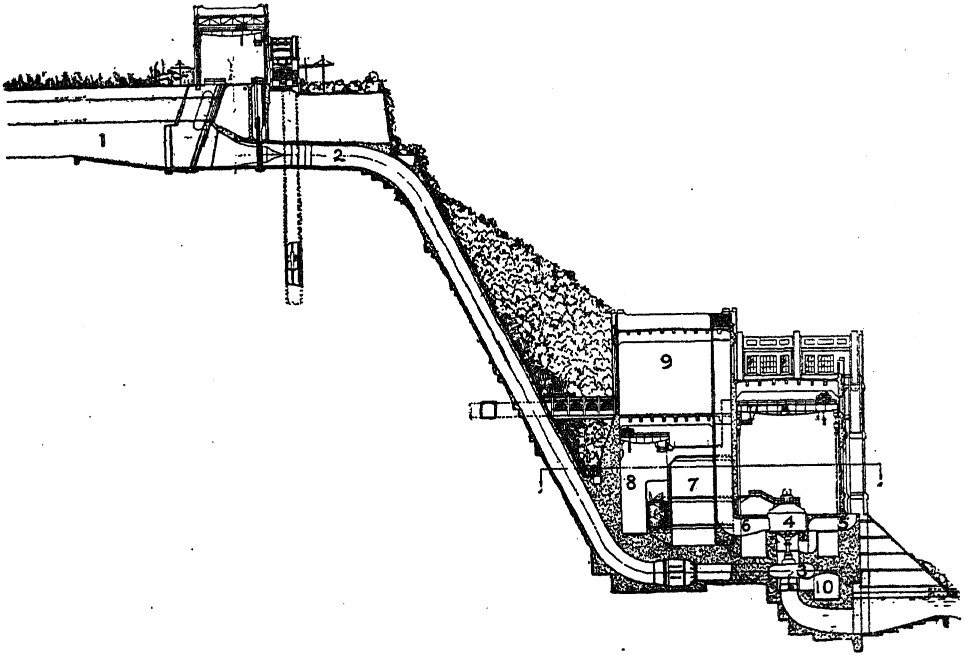
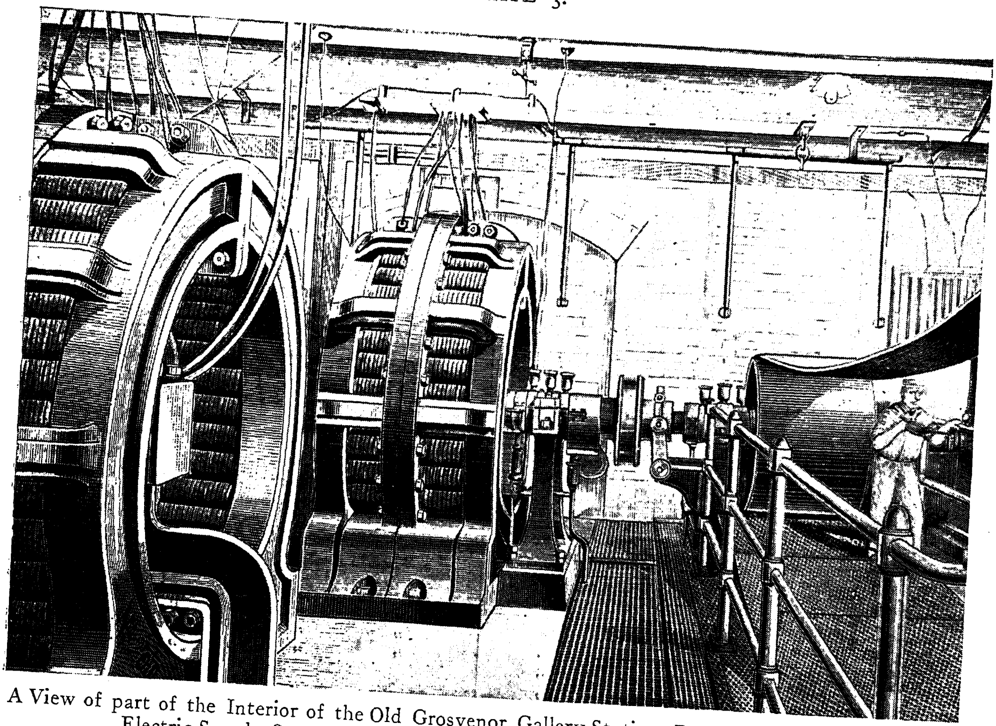


FIG. 5.—A Section showing the Penstock and Power House of the new large Power Station at Queenston, Niagara Falls. 2 is the penstock or water-tube, 3 the turbines, 4 the dynamos in the power house.

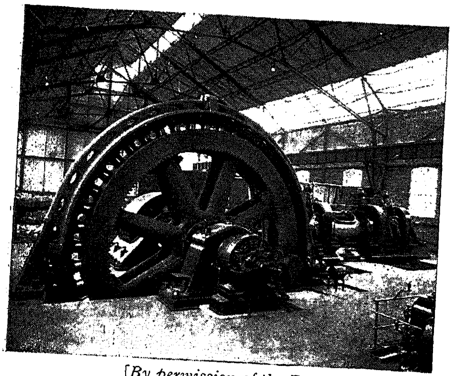
At the present time (1921) there are four companies which draw and distribute power from Niagara Falls, three operating on the Canadian and one on the American side. The former take 450,000 h.p. and the latter 350,000 h.p. from the Falls.

There is, however, another great scheme in hand on the Canadian side known as the Queenston-Chippawa Power Co., which has for its object to draw off another 500,000 h.p. and to utilise not merely the head of water of the Falls but the full drop of level between Lakes Erie and

PLATE 3.

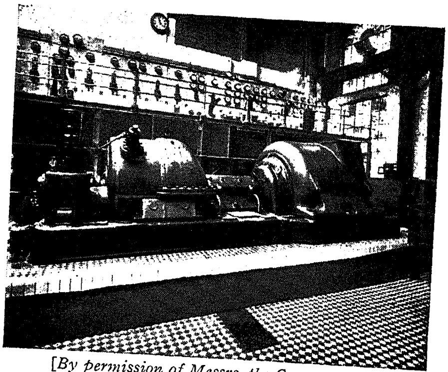


A View of part of the Interior of the Old Grosvenor Gallery Station, Bond Street, of the London Electric Supply Corporation, Ltd., showing two of the Ferranti Alternators.



[*By permission of the English Electric Co.*

A Three-phase Alternator in a Steel Works.



[*By permission of Messrs. the General Electric Co.*

A Turbo-alternator installed in a Power Station.

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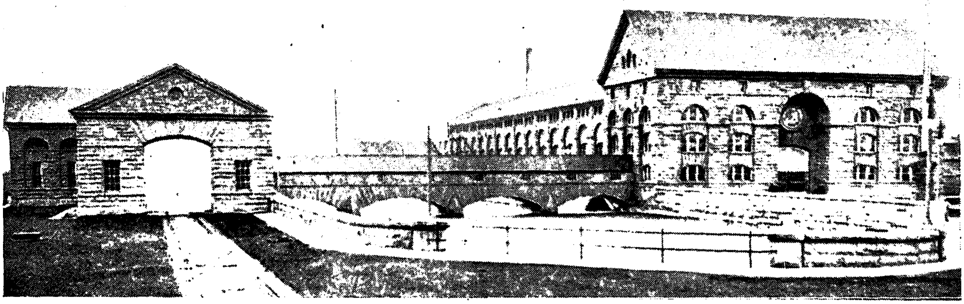
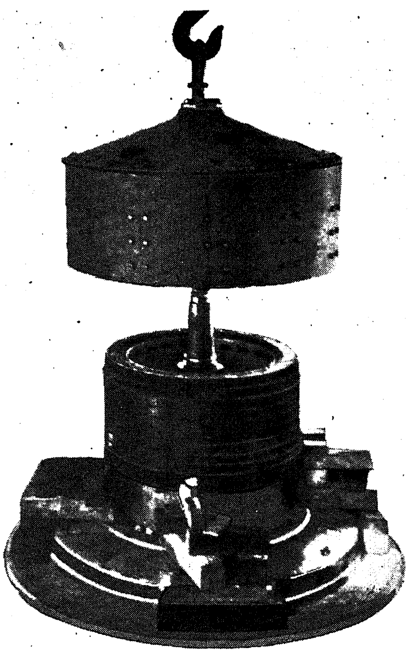
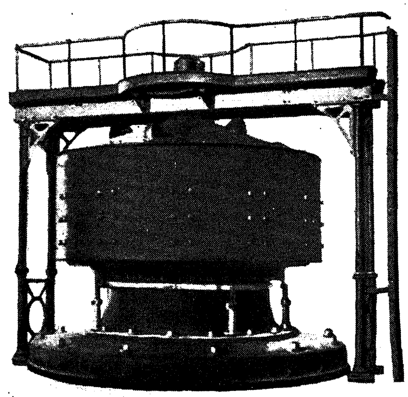
PLATE 4.



A View of one of the Niagara Falls Power Stations taking water from the Falls for Electric Supply.



A View of one of the 5,000 h.p. Two-phase Niagara Alternators with field magnet raised to show the armature.



A View of one of the 5,000 h.p. Niagara Power Station Alternators with field magnet in place.

[*To face page* 241.

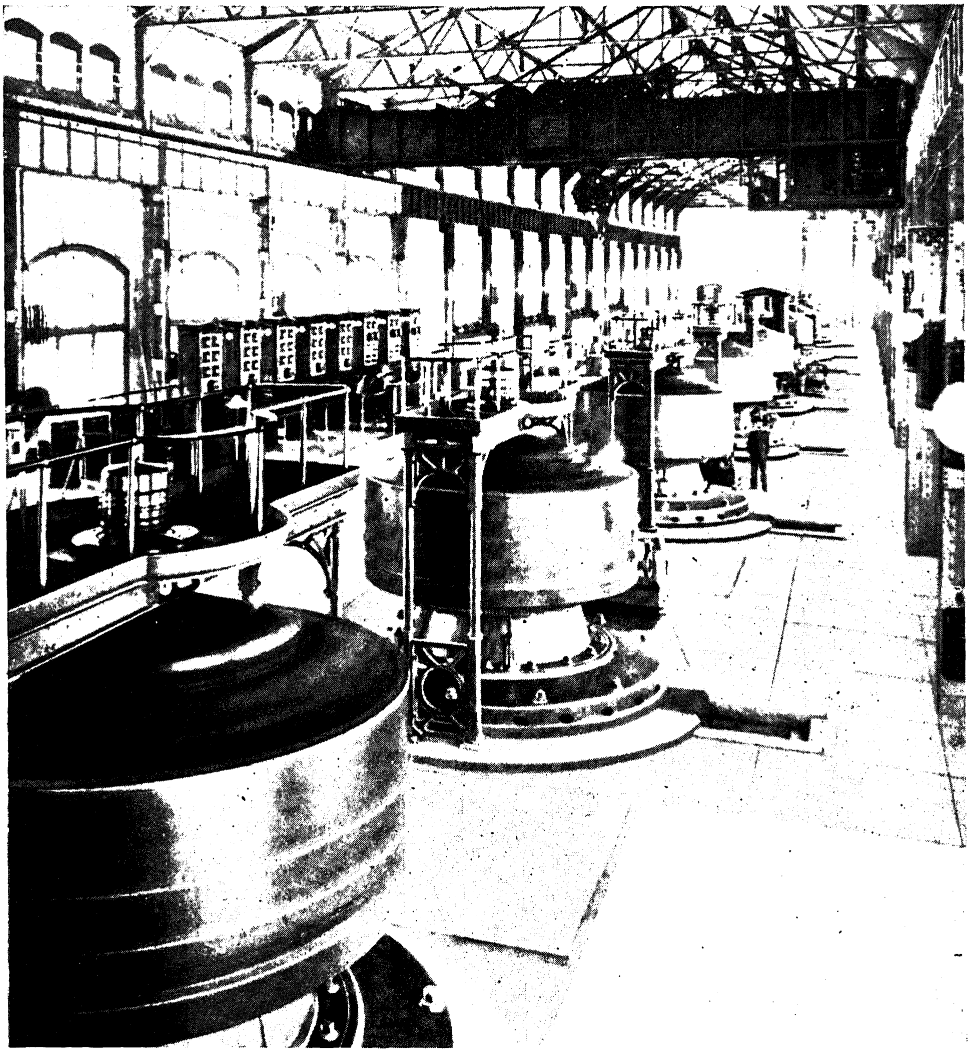
Ontario, which is nearly double that of the Fall alone. This involves cutting a canal thirteen miles long and diverting a large amount of the water to the edge of the gorge at Queenston. There it will fall through steel pipes 13 feet in diameter to a power station situated at the base of the cliff (see Fig. 5). It will then pass through turbines which will drive four colossal dynamos of 50,000 h.p., which will convert the mechanical energy of this immense mass of water falling through a height of 300 feet into electric current energy. Having done its work the water will be discharged into the lower rapids. It has been estimated that the whole power of Niagara Falls represents six million h.p. Up to date about one-eighth of this has been abstracted and used. It is hoped that this last scheme will enable 250,000 h.p. to be distributed by the end of 1922. Most of the large schemes for the electrical transmission of power which have been inaugurated during the last twenty years involve the generation of two- or three-phase alternating currents by alternators driven by steam or water power, the raising of the voltage by transformers to a high pressure, even 150,000 volts, depending on the distance of transmission and the reduction of this pressure at the receiving end of the line by step-down transformers. This power is then utilised for electric lighting, traction or motors (see Plate 6). It is generally the custom to employ the transmitted power to drive large two- or three-phase induction or asynchronous motors, made as described in Chapter II., and these are coupled directly to a direct-current generator which in turn supplies current for traction or lighting. This coupled motor generator is often called a rotary transformer (see Plate 11, page 137).

In places where water power is abundant, such as Switzerland, Norway, the South of France and the United States and Canada, millions of horse-power are now utilised in this manner.

In 1907 the author, accompanied by his colleague, Professor W. C. Clinton, paid a visit to some of the large power stations in Switzerland, and described the results in *The Engineering Supplement of the Times* for September 4th and 11th, 1907. One of the largest of these Swiss Stations is at Beznau on the Aar, near Baden in the north of Switzerland. It distributes 20,000 h.p. over an area of 800 square miles, including cities such as Zürich, Baden, Winterthur, Rheinfelden, and others.

A barrage was constructed across the Aar about four and a half miles from its confluence with the Rhine, and above this a canal cut to lead the water to station buildings above a quarter of a mile away. The water service is regulated by gates in the barrage and at the canal entrance. At the station the available head of water varies from 11 to 19 feet. The station is a large building 700 feet long and 35 feet wide. In it are installed eleven low-fall turbines with vertical axes, by Bell & Co., of Kriens; six of 1,000 h.p. and five of 1,200 h.p. These are coupled direct to three-phase alternators, by Brown, Boveri & Co., of Baden, with fixed horizontal ring armatures, giving a three-phase current at 8,000 volts. The revolving part is the field magnet, the speed being 66·7 r.p.m. These fields are excited by two D.C. ten pole machines of 400 h.p., furnishing 800 amperes at 250 volts. In addition to this hydro-electric plant, there are two steam turbine sets of 3,000 h.p. each, by Brown, Boveri & Co. The whole of these machines are lubricated by a high pressure oil service. The alternators supply on to bus bars of bare copper strip, and the regulation of the alternators is conducted from a switch gallery at the end of the machine hall. The current is raised in voltage for long-distance transmission to 26,000 volts by six step-up transformers of 2,000 kilowatt size. The near places are served direct off the bus bars at 8,000 volts. The distribution is by overhead stranded copper conductors 7—8 millimetres in diameter, carried on triple shed porcelain insulators fixed to wooden or iron lattice poles. Feeder lines run to Rheinfelden (thirty miles), conveying 3,000 h.p.; and to Entfelden (twenty-one miles), conveying 1,600 h.p.; to Seebach (twenty-three miles). Two other feeders convey 11,500 h.p., which is distributed to Zürich (4,000 h.p.), to Grüningen (4,800 h.p.), and to Winterthur (2,700 h.p.). In addition, 8,000-volt feeders run to Baden, Wettingen, and other small places in the neighbourhood of Beznau. At these places transformer stations exist which step-down the currents from 26,000 to 8,000 volts and then to 120 volts for lighting or 600 for traction purposes. One thing which strikes the English electrician is the boldness with which these large amounts of power are conveyed on single feeders of copper wire 6—8 millimetres in diameter carried on wooden posts by porcelain insulators; but the precautions taken are such that accidents or interruptions are rare.

PLATE 5.



A View of the Interior of one of the Niagara Falls Power Stations showing the 5,000 h.p. Alternators which are driven by water turbines in a pit 150 feet below the level of the floor of this station.

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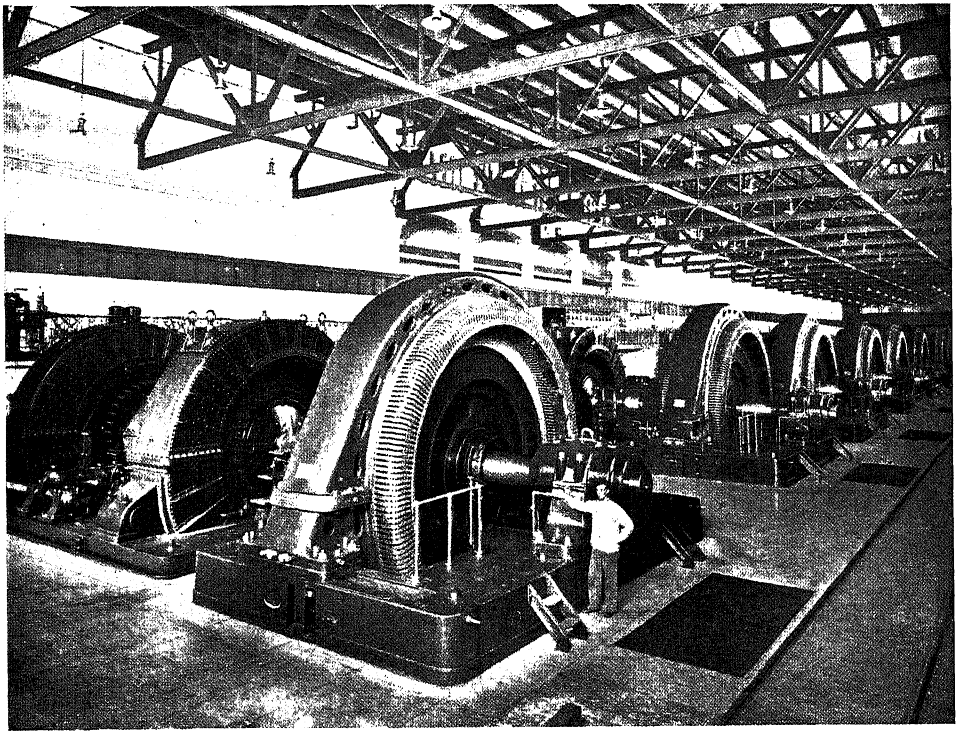
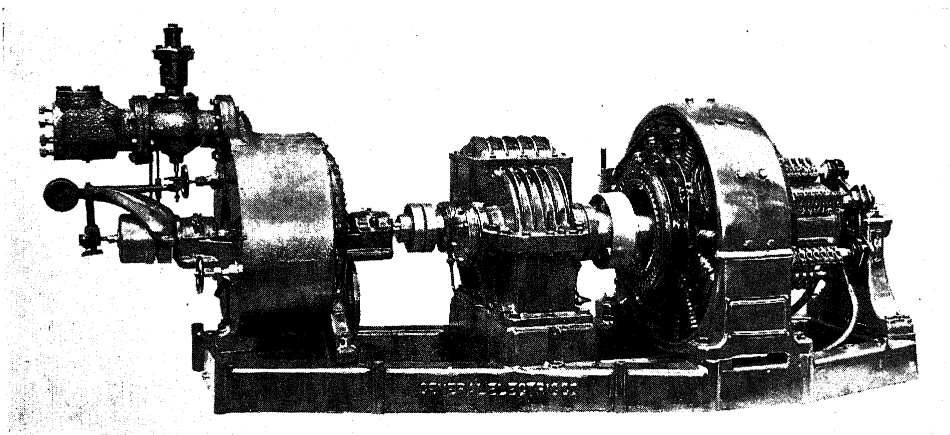
PLATE 6.



Interior View of the Generating Station, Ontario Power Co., Canada, showing the Alternators driven by Water Turbines taking power from Niagara Falls and distributing 34,000 h.p. throughout the Province of Ontario.



A Direct-current Dynamo for Low-pressure Electric Supply driven by a Curtis Steam Turbine. The turbine is geared to the dynamo by a reduction speed gear.

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To preserve the lines and machines from the effect of lightning discharges the following simple means are employed. At the generating station the lines are connected to earth through a long jet of water. The line is connected to a water jet supplied from a tank kept full of water by means of an indiarubber pipe, and the water falls into a well-earthed tank; or else water is supplied under pressure to a jet throwing it vertically upwards, so that it strikes against a metal plate connected to the line. The high-pressure line is thus earthed through a flowing column of water 2 feet or so in length and, perhaps, half a square inch in section. This has the effect of keeping the line from becoming statically charged. In addition, the line is furnished at various places with a pair of curved horn-shaped lightning dischargers (*blitzhörner*), one wire being to the line and the other to earth, so that the alternating arc following a discharge is automatically extinguished (see Fig. 6).

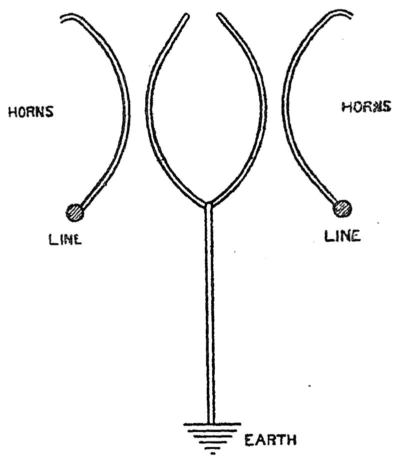


Fig. 6.—Lightning Horns to protect Overhead Electric Power Lines. They consist of a pair of curved metal wires, one of which is connected to the electric line (shown in section) and the other to the earth. If lightning strikes the horns it jumps across from one horn to the earth, but the electric arc caused by the line current following it is soon blown out.

Another precaution against short circuiting is the provision of quick break oil switches, which are controlled by motors set in operation by time relays of the following construction. An aluminium disc rotates on a horizontal axis and at one place passes between the jaws of an electro-magnet, the windings of which are a shunt on a part of the line. This disc, therefore, tends to rotate by the action of electro-magnetic repulsion. The rotation is resisted by a balance weight which keeps the disc at rest under the action of the normal or *maximum* line current. If this current is exceeded the disc begins to rotate, and, after turning through a certain angle in a certain determined time, it closes a contact which sets in operation an electric motor which in turn opens the oil switch. The line circuit is therefore opened after a certain time, which can be arranged, and

saves the generators from a short circuit but does not interrupt for a merely momentary overload.

Another feature tending to safety is the elaborate care with which the high tension switchboards are constructed. The circuits are all run with bare copper rod or strip carried on porcelain insulators, the pins of which are built into a partitioned wall, so that the various parts of the bus bars as well as the main switches, main cut-outs, change-over switches, etc., are all isolated in separate fireproof cells or chambers built of cement open to inspection, but sufficiently recessed to prevent arcing over.

Another large recent hydro-electric station is that which supplies the town and neighbourhood of Lucerne with electric energy for lighting and traction transmitted from a station at Obermatt, near Engelberg. The water reservoir in this case is situated in the upland valley of Engelberg and is an artificial reservoir having a capacity of 70,000 cubic metres of water. It is kept supplied by the Engelberger Aa and other streams flowing down into the valley. From the lake an underground closed-in conduit, 2,560 metres in length, leads to a water tower at which the penstocks or fall tubes commence. From this point two tubes, 1 metre in diameter, are laid down the side of the hill, provision being made for two more tubes when required. These tubes have a total length of 620 metres and a level difference of 300 metres between top and bottom. At the water tower are placed the necessary regulating valves for controlling or arresting the fall of water. The tubes are of Siemens-Martin sheet-steel triple riveted. They are anchored at top, bottom, and at three intermediate points in masses of concrete, and are provided at three places with expansion joints. The walls of these tubes are from 16—26 millimetres in thickness, and are constructed in 8-metre lengths with flanged joints.

The power station is a stone building situated at Obermatt, in close contiguity to the Stanstad-Engelberg Electric Railway, a few kilometres from the Engelberg terminus. The main penstocks pass alongside of the station and from them branches are taken to the turbines. The machine hall is 180 feet long and 45 feet wide. There are at present installed in it four turbine-alternator sets each of 2,000 h.p., with space for two more. The turbines are Pelton wheels, having a speed of 300 r.p.m., auto-

matically regulated by hydraulic governors. The alternators give a three-phase current, with a frequency of 50 and voltage of 6,000. They were built by the Oerlikon Maschinenfabrik in 1904, and the turbines by Th. Bell & Co., of Kriens.

The water supplied to the turbines after doing its work returned by a canal to the Engelbergerbach. The alternators have fixed armatures and revolving fields excited by separate D.C. machines at 110 volts. The three-phase current so generated is raised from 6,000 to 27,000 volts for transmission to Lucerne by oil-insulated water-cooled transformers. The transformers are star-connected in groups of four, three 700-kilovolt transformers being connected for the three-phase service and one being a spare transformer. These transformers can be connected so as to give a three-phase current for the power service and a single-phase current for the lighting service on separate high tension lines. From this station proceed three three-phase lines each of three conductors, one for lighting, the second for power in Lucerne, and the third for light and power in Unterwalden. Also a short line (about three miles in length) conveys about 200 kilowatts to Engelberg and about 200 kilowatts is distributed to smaller places in Nid and Oberwalden cantons. The main portion of the power —viz., 7,000 to 8,000 h.p.—is conveyed by the above-mentioned triple conductors to a transformer and distributing station in Lucerne. These conductors are hard-drawn copper wires, 8 millimetres in diameter, and are carried on triple shed porcelain insulators, which are in turn fastened to varnished wooden rods fixed to 470 iron lattice towers. These last are 56 feet high, the bases being set in concrete, and are spaced from 200 feet to 400 feet apart. In a few cases these towers are carried on iron brackets projecting from the rocky banks of parts of the lake of Lucerne. This over-head line crosses in several places the Stanstad-Engelberg and the Brunig railways. The total length of line is seventeen and a half miles.

To the uninitiated observer, if it were not for the substantial appearance of the lattice towers, it might be mistaken for a telegraph line, whereas it conveys 8,000 horse-power at a pressure of 27,000 volts.

In the Obermatt station the lines terminated in the elaborate switchboard arrangements characteristic of these recent high tension stations. The " switchboard " is in fact the name for a set of partitioned galleries

divided into fireproof chambers or recesses through which the bus bars are carried and in which are insulated the switch-gear cut-outs and other regulating apparatus. The general scheme of connections is as follows. Each generator sends its current into one of a pair of ring bus bars, one of these is a triple- or three-phase and the other a double or single-phase. Each alternator is connected to one of the bus bars through cut-outs, isolating switches, and *maximum* oil switches. Various sections of these bus bars can be isolated if necessary. To the bus bars are also connected the 6,000 volt or low tension sides of the group of transformers, and the high tension of 27,000 volt sides are similarly connected as required to a second set of double or triple bus bars for extra high tension, to which last the three transmission lines are united. These transformers and alternators are protected from lightning discharges falling on the line by the earthing of the line through water jets as above described, and also by the application of the usual horn-shaped lightning protectors.

Each of these high tension transformers is isolated in its own fireproof chamber closed by an iron roller shutter. Ingenious devices exist for ringing an electric bell and calling attention if the water circulation through each transformer case is arrested by any accident. There are time relays, made as already described, which operate oil switches by means of motors and cut-out any line in case of a short circuit lasting longer than a certain assigned time.

All switching, bus bars, and regulating gear is contained in an annexe of three floors adjacent to the main machinery hall. On the ground floor are placed the low tension bus bars and gear for the 6,000 volt circuit, on the first floor the bus bars and switches for the 27,000 volt circuits, and on the second or top floor the switches, cut-outs, and lightning protectors for the outgoing lines. The perfection of all these arrangements is so great and the details so well thought out that the actuating labour is reduced to a *minimum*. On visiting these large Swiss hydro-electric stations one is struck with the small staff left in charge—two, or at most three, men work the whole installation. In fact, there is nothing to do. The turbines are self-regulating as to speed, and the necessary throwing in or out of alternators and transformers on changes of lines is made with the utmost ease and safety.

The current so generated and transmitted is distributed from a transformer station called the Steghof station in Lucerne, a few minutes' walk from the railway station. This is a substantial three-storey brick and stone building, into the top floor of which the above said high tension lines enter. The current is here transformed down from 25,000 volts by three-phase oil-insulated transformers. The general arrangement of the bus bar and transformer plant at this sub-station is much the same as at the Obermatt generating station. The three high tension lines can be connected as required to a triple or double ring bus bar, and from these connections pass to the step-down transformers. These last supply direct on to the town distributing lines or feed three-phase motors coupled to 575 volt continuous current dynamos which supply the current for the Lucerne street electric cars. A number of transformers, each isolated in its own fire-proof chambers, take the current at 25,000 volts and transform it down to 2,650 volts three-phase. Those giving a service for light are 700 k.v.a. size and those for power 300 k.v.a. In addition, there are three sets of coupled-three-phase motors and D.C. generators of 300 kilowatt size for creating the currents for traction.

From this station current is distributed by underground cables to other smaller transformer stations, and to the large hotels and buildings in Lucerne, where it is employed for light and power, and the continuous current by overhead wires to the tramway system.

In addition there are two other transformer stations, one at Stanstad and one at Kriens, fed by the above-named high tension lines. In these the 27,000 volt current is stepped down in a similar manner for distribution for light and power in the neighbourhood of Stanstad and Kriens.

A few details of the cost of the above installation may be given. They are as follows :—

	£
Land, water-rights, and way-leaves	9,940
Buildings, foundations	69,874
Machinery, turbines, etc.	25,120
Electrical plant	72,072
Overhead conductors	10,968
General and other expenses	20,000
Total capital outlay	£207,974

As the station can deliver 6,000 kilowatts the above outlay works out at about £35 per kilowatt.

The concession for the Engelberg water rights runs for sixty years at a payment of £200 per annum for the first five years, amounting to £400 per annum after the sixteenth year. It will thus be seen that the actual generating costs are small compared with the interest on the capital outlay. This large undertaking was begun in 1903 and completed in July, 1905, since which time the supply of electric energy has been uninterruptedly continued. At the end of 1905 there were 34,000 10 c.p. glow lamps, 210 arc lamps, and 210 motors installed in Lucerne alone, numbers largely increased since the supply began.

A third important hydro-electric supply station is that situated at Spiezmoos, on the Lake of Thun, called the Kander station. This is operated by water taken from the River Kander, which flows down the valley from Kandersteg and falls into the Lake of Thun. About one kilometre above the bridge across the Kander which connects Spiez and Wimmis a dam was built, and from just above this point a canal, 680 metres in length, leads to a reservoir. From this point an iron pipe, 224 metres long and 1·8 metres diameter, leads to a water tower, from which a second iron tube 400 metres long and 1·6 metres diameter, the walls of which are 5 millimetres thick at top and 11 millimetres at the bottom, leads to a second water tower. At the first-named water tower a large reservoir or water storage is being constructed, having a capacity of 400,000 cubic metres. From the last-named water tower two penstocks or iron pipes descend the hillside for a distance of 365 metres, having a vertical fall of 65 metres and a diameter of 1·6 metres.

The station is a substantial stone building about 100 feet by 33 feet, situated at the edge of the Lake of Thun. It contains six water-turbine alternator sets, five of 1,300 h.p. and one of 4,000 h.p. The turbines, by Escher-Wyss & Co., of Zürich, are of the inward flow type and are coupled direct to three-phase alternators by Brown, Boveri & Co., of Baden. These generate current at 4,000 volts. The small generators have exciters on the same shaft, the 4,000 h.p. machine is separately excited by a 300 h.p. 150 volt D.C. turbine generator. There are also two 20 h.p. exciter sets as a reserve for the smaller machines each driven by a Pelton

wheel. The turbines are self-regulated as to speed by governors and water relays. Overlooking the machine room is a switch gallery from which the machines are controlled and "parallelised," and behind this is the switchboard proper, the arrangements of which resemble generally those at the Obermatt station already described. The three-phase generators feed into a ring bus bar system and from this are taken off feeders direct or connections to high tension transformers to raise the pressure for long-distance transmission.

From this station current is supplied for the electric lighting of Berne (twenty miles), Interlaken (twelve miles), Burgdorf (twenty-five miles), Beatenberg, and towns in the Simmenthal and Kanderthal, and also for the Burgdorf-Thun Railway, about twenty-five miles in length, the total supply at present being about 4,000 h.p. The switchboard at the Kander station contains six panels divided up as above. The arrangements already described for switching in and out the transformers and overhead lines are employed, and also time relays operating oil switches for opening the circuits under load in case of short circuit, and the lightning protectors for securing the generating plant from storm discharges.

For transmission to Berne and the Burgdorf-Thun Railway the station voltage is raised from 4,000 to 16,000 volts by oil-insulated and water-cooled transformers, two sets of three single-phase 500 kilowatt transformers, with one reserve transformer in each set, being employed. For places within 5 kilometres the current is supplied at 4,000 volts direct from the bus bars. This energy is transmitted on overhead conductors carried on triple shed porcelain insulators fixed to wooden or iron lattice poles of the usual pattern. At Berne the current is fed into a ring main surrounding the city, which supplies four transformer stations, in each of which there are seven single-phase oil-insulated 50 kilowatt transformers. Here the current is transformed down to 3,000 volts and distributed by underground mains to other smaller transformer stations in the town, where the voltage is again reduced to 250 for motors and 125 for glow lamps.

In the case of the Burgdorf-Thun Railway there are fourteen transformer stations along the line, where the 16,000 volt current is reduced to 750 volts and supplied by two overhead lines to the three-phase motors on

the locomotives, the rails forming the third line. On these locomotives there are two 150 h.p. motors with single reduction gear. In addition to two locomotives there are six electric cars, each having four motors of 60 h.p. each. The speed is regulated by the insertion of resistance in the rotor circuits.

The above described typical three-phase stations have been equipped by the well-known firms, Messrs. Brown, Boveri & Co., and the Oerlikon Company, and represent the most advanced practice in three-phase work. There is, however, another large system of supply in Switzerland conducted on the high tension direct current or Thury system, which is of considerable interest. This supplies the city of Lausanne and district from St. Maurice in the Rhone Valley.

The station is situated at Bois Noir, a few minutes' walk from the St. Maurice railway station on the Rhone Valley Railway, and by it 5,000 h.p. is transmitted 56 kilometres, or thirty-five miles, to Lausanne and the neighbourhood. The water is taken from the river Rhone, and is conveyed to the power station by a wrought-iron pipe 2·8 metres in diameter and 470 metres long. The available head of water is 30 metres. This supply station was constructed and inaugurated in 1902 by the Compagnie de l'Industrie Electrique de Geneve, and owes its chief interest to the adoption of the Thury system of supply by constant continuous current at high pressure. The current is 150 amperes, and the *maximum* voltage 23,000 volts.

In the station buildings at St. Maurice there are ten continuous current six-pole dynamos, which are coupled in pairs to turbines built by Escher-Wyss, of Zürich. Each dynamo has a voltage of 2,300 volts when fully excited, and the whole or some of these machines can be joined in series as required. To render this safe each dynamo is bedded on porcelain insulators sunk in an asphalte concrete foundation, which perfectly insulates the machines, and the dynamos are likewise insulated from the turbines by insulating couplings.

The dynamos are provided with an ingenious relay, which regulates the voltage by shifting the brushes and inserting resistance of the fields so as to keep a constant current, and each dynamo can by a simple switch be short circuited and taken out of series. The current so generated is

conveyed by an overhead line of stranded cable 150 square millimetres in section to Lausanne.

The station also contains two 120-h.p. three-phase alternators for the electric lighting of St. Maurice and of the station itself.

Each of the five large turbines takes 3 cubic metres of water per second when fully loaded, and they are self-regulated by hydraulic governors, the control valve cylinder being charged with oil, as the Rhone water has too much suspended matter in it for this purpose.

The corresponding transformer station is at Pierre de Plan, a suburb of Lausanne. To this building the high tension line is led, and it contains ten high voltage constant current D.C. motors of 440 h.p. each, 300 r.p.m. and 150 amperes. The motors are six-pole, the brushes being shifted automatically with the load, and the fields varied by a governor regulator so as to keep a constant speed.

Each motor is coupled direct by an insulating coupling to a generator, either a three-phase or a direct current machine, for 600 volts and 442 amperes. There are four three-phase alternators with an E.M.F. of 3,000 volts each, giving a current of 60 amperes at a frequency of fifty, with a speed of 300 r.p.m.

The direct current machines work the Lausanne electric street cars and the three-phase machines supply current to transformer sub-stations in and around Lausanne for lighting and power. In addition to the above six generators there are five other generators which can be driven either by motors actuated by current from St. Maurice, or by being coupled to steam engines of 550 h.p. by Sulzer Frères, of Winterthur. A 1,500 h.p. steam turbine by Brown, Boveri & Co. is also being put in as a reserve. The process of starting up a motor is to insert it in the circuit whilst standing still with the brushes in a neutral position. The brushes are then shifted over until the motor starts up. From a switch-board gallery the whole of the generators are controlled and the currents distributed as above explained. The weak point in the system is undoubtedly the dependence of the supply upon a single transmission line from St. Maurice. This necessitates the provision of steam engines at Lausanne as a reserve with all the necessary stand-by losses.

Although the ingenuity of the devices connected with the working

of the Thury system of power transmission by continuous constant current is remarkable, it is obvious that the line losses are a constant quantity, and therefore the efficiency at low loads must be small. Hence it is not surprising that in some of the latest and largest schemes on foot the three-phase alternating system should have been preferred. One of the most important of these is the new power station erected near Thusis at the entrance to the Albula Pass. This conveys 22,000 h.p. at a pressure of 45,000 volts for a distance of eighty-five miles to supply Zürich and the neighbourhood with electric power. The power is taken up by Pelton turbines, the available head of water being 480 feet fall. The three-phase generators, switch gear and transmission lines (in duplicate all the way) were provided by the Oerlikon Company, the transformers by Brown, Boveri & Co., of Baden, and the continuous current generators at the receiving end by the Compagnie de l'Industrie Electrique, of Geneva.

It would be impossible to describe in these pages even a small fraction of the electric supply stations which exist at present (1920) in the world. We may divide them, however, into certain well marked classes.

There are, first, in-town stations supplying closely populated city districts, and these are always on the three-wire direct current system with 440 volts or so between the outer conductors and 220 volts or so on each side for lamps and small motors, whilst larger motors are worked off the outer conductors (see Plate 7, lower diagram).

As such stations are in places where land is valuable, they are often built in several stories with engines and dynamos in the basement and boilers on upper floors. Very large multiplex direct-current generators are used, coupled direct to reciprocating steam engines or, more frequently, to steam turbines, such as those of Parsons, Curtis or Rateau (see Plates 6 and 7, pages 243 and 254).

For the sake of rapid steam raising in case of fogs water-tube boilers such as that of Babcock are very generally used. To aid in keeping a constant load and as a stand-by to maintain electric supply in case the steam supply is interrupted, it is very usual to provide direct current low-pressure supply stations with storage batteries, which are charged by the generators at time of light load and then discharge on to the circuits during the "peak hours" or heavy demand time, or else act as a reserve

or to maintain supply during the small hours of the night and enable the engine-dynamo plant to be shut down.

Hence a little information must be given on the development of the storage cell or secondary battery.

The early history of the secondary cell may be passed in review in a very few words. The year after Volta had given to the world (in 1799) the voltaic cell for generating continuous electric current, Nicholson and Carlisle noticed that bubbles of gas were evolved from gold wires dipped into salt water when these wires were connected to a voltaic battery, and that the bubbles were oxygen and hydrogen gases.

Gautherot in 1801, and Ritter in 1803, observed that silver, platinum and gold wires, after being so used as the electrodes in a voltameter, could themselves act as the elements of a voltaic cell when placed in acidulated water, and give back a brief secondary current when disconnected from the battery and connected to a galvanometer.

Little was added to our knowledge until 1859, when a French chemist, Planté, took up the subject again, and after careful examination of the behaviour of different metals, showed that lead plates possessed peculiar properties when used as electrodes in a secondary cell.

If two clean lead plates are placed in dilute sulphuric acid and connected to a voltaic battery, at the moment of completing the circuit we find bubbles of hydrogen arising from one lead plate but nothing from the other. If, however, we look presently at this last plate we see that its surface is covered with a brown film. This is a thin layer of peroxide of lead. If these electrodes are then connected with a galvanometer they give a strong but brief reverse secondary current which comes out in the opposite direction to that in which the charging current went in. Hence the arrangement enables us to store up energy, and is called a storage cell.

Planté made the important discovery that although the efficiency of a lead secondary cell was very small to begin with, probably not greater than 3 or 4 per cent., it could be enormously increased by a certain process called *forming the cell.* The operation was as follows :—

The cell was first charged in one direction and then allowed to rest; it was then discharged and charged in the opposite direction and again allowed to rest, and the process repeated many times. The result was to

immensely increase the power of the lead plates to take up electric energy. The explanation of this is as follows :—

When the current is first passed in one direction the surface of the negative electrode becomes covered with a thin film of peroxide of lead (PbO_2), and as soon as this is complete any further delivery of current merely evolves bubbles of oxygen against that plate. If the plate is, however, allowed to rest a further chemical action goes on called *local action*, which results in the production of sulphate of lead ($PbSO_4$). Peroxide of lead is a conductor, and it is highly electronegative to other metals, even to lead, and it forms with lead a voltaic couple when placed in dilute sulphuric acid.

It is a familiar fact that pure zinc is insoluble in dilute sulphuric acid, but ordinary zinc containing particles of iron and other metals is freely soluble by dilute sulphuric acid by reason of the formation of small local galvanic couples.

This effect can be shown and exaggerated by putting little particles of copper upon a little zinc plate ; such a plate rapidly dissolves with evolution of hydrogen in dilute acid.

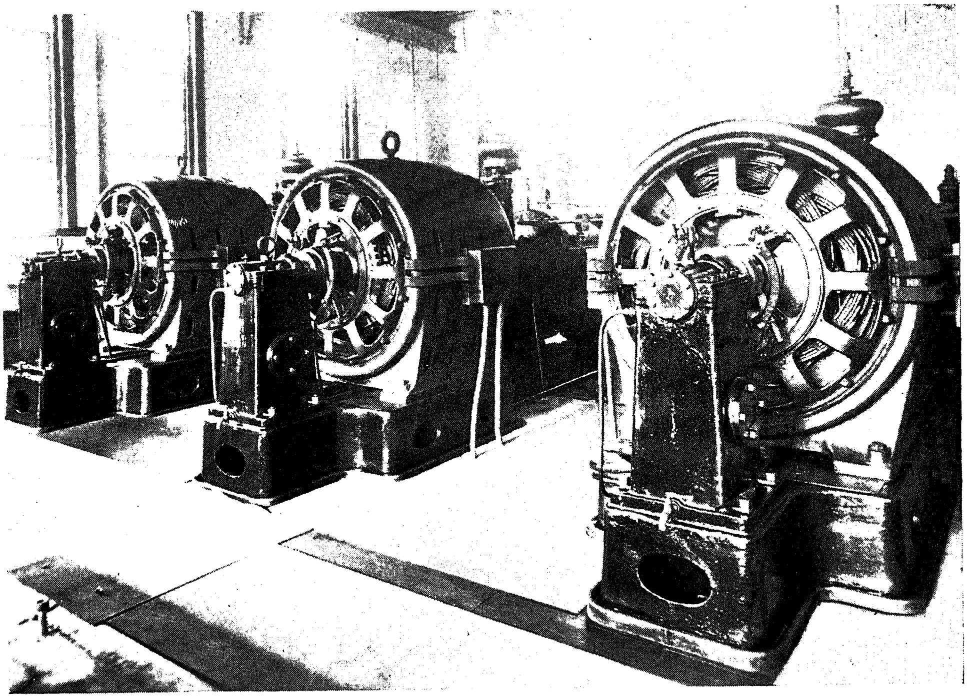
Just in the same way pure lead is practically insoluble in dilute sulphuric acid, but when covered over with patches of peroxide of lead will dissolve in dilute sulphuric acid with the formation of sulphate of lead.

It should be noticed in passing that there are three well-known oxides of lead, litharge (PbO), red lead (Pb_3O_4), and peroxide of lead (PbO_2), and all of these oxides when placed in dilute sulphuric acid are converted into sulphate of lead or mixtures of sulphate of lead and peroxide of lead.

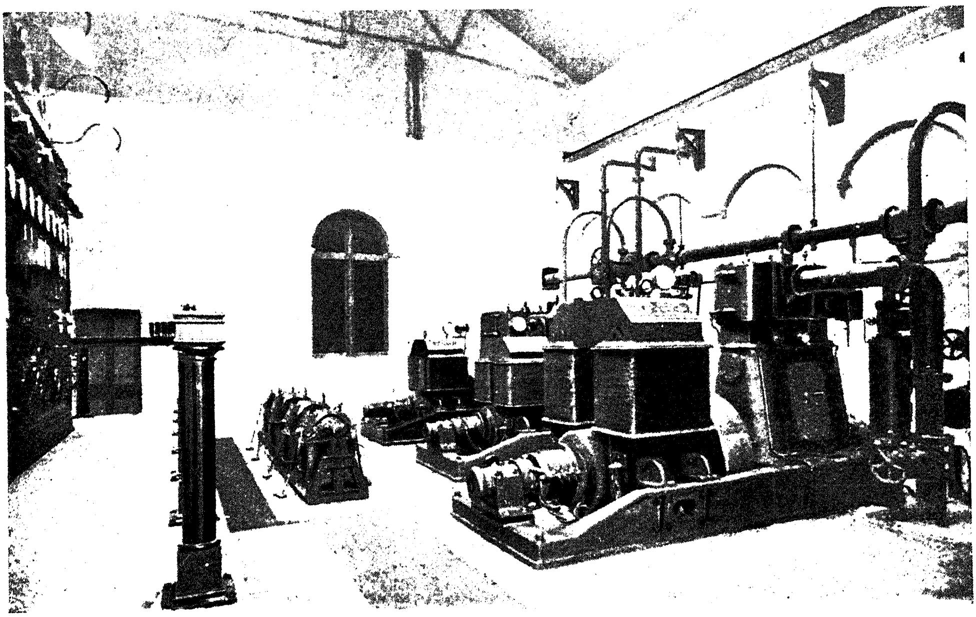
Hence the result of Planté's period of rest is to produce by local action a certain quantity of sulphate of lead on the peroxide plate. On reversing the current the peroxide of lead and the sulphate of lead are electrolysed into metallic lead, and that lead is left in a finely divided condition called spongy lead, closely adhering to the plate. At the same time the other lead plate is converted superficially into peroxide of lead.

Hence Planté's operations have for the result the conversion of two lead plates into a condition in which they become very porous, and the action on the charging current is then not merely to produce a thin film of peroxide of lead on the negative electrode, but to transform it to a con-

PLATE 7.



Westinghouse 400 Kilowatt Alternators supplying current at 440 volts driven by Steam Turbines. Installed in works of the Westinghouse Air Brake Co., Wilmerding, Pa., U.S.A.



A View of part of the Interior of a Low Voltage Electric Supply Station at Bootle, Cumberland, England. The supply is on the three-wire (2 × 220 volts) system. The view shows the direct-coupled steam dynamos (on right) the boosters and balancers (centre) and part of the switchboard (on the left).

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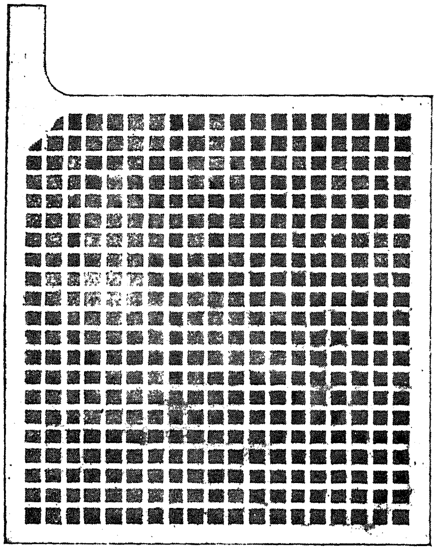
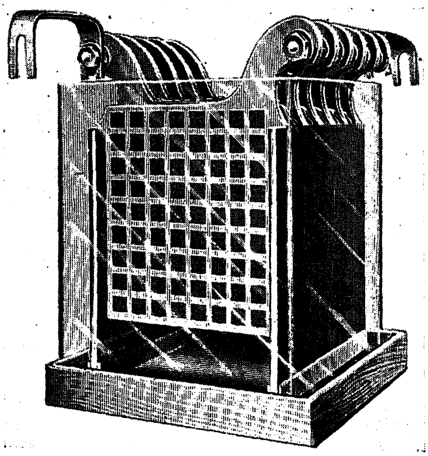
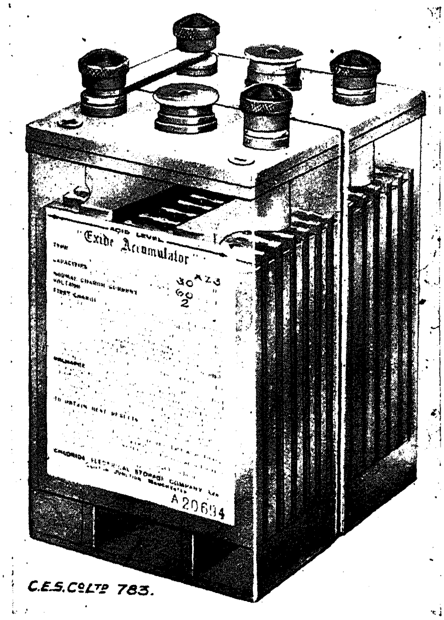
PLATE 8.



Packed Grid Lead Plate used in Storage Cells.



A Supply Station type Storage Cell or Accumulator comprising lead plates, positive and negative, inter-spaced and placed in dilute sulphuric acid.



[*By permission of the Chloride Electrical Storage Co., Ltd.*

A Portable Lead Plate Storage Cell or Accumulator.

[*To face page* 255.

siderable depth into a crystalline adherent layer of peroxide of lead. Planté found that this process was assisted by a previous treatment of the lead plates with nitric acid, and since his time many inventors have devised what are called *forming solutions* which act on the lead and help to make it porous. Lead plates which have been so treated and then formed are called *Planté plates*, and a pair of properly prepared Planté plates present the following appearance :—

A plate which has been the negative electrode at the first charge, and which is now called the positive secondary plate, presents a deep chocolate-coloured appearance, being converted into a dense adherent layer of peroxide of lead. The other plate, now called the negative plate, shows a kind of elephant grey appearance, and the lead surface is rough and reduced to a porous state, being covered with a dense adherent film of lead sponge.

Planté's experiments did not at that time find much industrial application, and it was not until 1881 that a fresh impetus was given to the study of the secondary cell by a discovery due to another French inventor, C. Faure. Faure's invention was as follows :—

Instead of forming the peroxide of lead film out of the lead plates by a slow process like Planté's, he enormously quickened it by putting on to the plates ready-made red lead. His first invention was as follows :— A lead plate was put horizontally into a dish, and on to it was sprinkled a thick layer of red lead; then a piece of flannel was laid upon the red lead, followed by a second layer of red lead and a second lead plate; the dish was then filled up with dilute sulphuric acid.

This arrangement was found to have remarkable power of taking up electric energy, and soon after the date of Faure's first patent public attention was drawn to it by a so-called wonderful box brought over from Paris to Glasgow, said to contain one million foot-pounds of energy. Lord Kelvin, then Sir W. Thomson, wrote an enthusiastic letter to *The Times*, and the public imagination was correspondingly excited concerning the new invention.

Faure's invention (covered by a British Patent, No. 129 of January 11th, 1881) was, however, very imperfect. The flannel was found to be soon destroyed by the acid, and if a porous clay partition was used instead,

it greatly increased the resistance of the cell. Faure made other improvements, using felt or asbestos card (British Patent, No. 1676 of 1881) for keeping the active material—that is, the red lead—on the plate. The invention, however, which put a fresh face on matters was Sir Joseph Swan's invention of the lead grid (British Specification No. 2272 of 1881), in which a lead reticulated plate had its interstices filled up with a paste made of red lead and dilute sulphuric acid (see Plate 8, page 255, upper diagram). Swan also patented at the same time a form of plate in which the active material was lodged on shelves, as it were, formed on a lead plate.

Other inventions then quickly followed, the object of inventors being to make effective arrangements to keep the active material on the plate in close contact with the lead support.

Briefly speaking, we may say that after formation or charging we have two lead plates, one of which carries on it a layer of peroxide of lead, and the other of which is converted superficially into a porous or spongy variety of lead. If these plates are placed in dilute sulphuric acid and connected by a wire, they generate an electric current. The peroxide plate (positive) acts like the copper or carbon plate in a voltaic cell, and the spongy lead plate (negative) like the zinc plate of a voltaic cell (see Plate 8). During the production of the current both plates are converted superficially into sulphate of lead. During this discharge the cell has an electromotive force of 2 volts or a little more, and it gives out a certain amount of electric energy reckoned in watt-hours per pound weight of plates. To re-charge the cell an impressed E.M.F. of 2·5 volts is required.

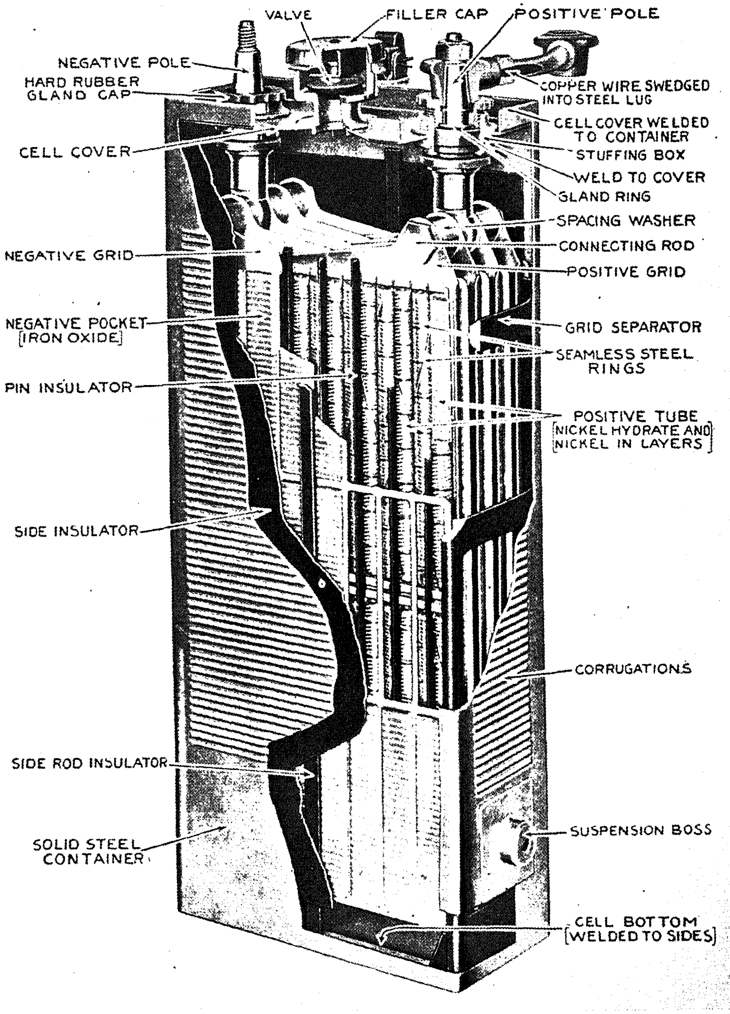
The quantity of electricity contained in a secondary cell is measured in ampere-hours, and since the useful discharge voltage is 2 volts, we may say that the ampere-hour capacity is numerically half the watt-hour energy storage.

For each type of cell there is a maximum rate of safe discharge in amperes which if exceeded will injure the cell.

A very usual rate of discharge is 4 to 5 amperes per square foot of total positive plate surface, but it may be taken up to 50 amperes per square foot.

The theoretical equivalent of 1 lb. of lead peroxide is 100 ampere-hours, or if we suppose two plates, each weighing $\frac{1}{2}$ lb., one wholly com-

PLATE 9.



Edison's Nickel-Iron Storage Cell. The elements are nickel peroxide and spongy iron in a solution of caustic potash. The cell is in a corrugated steel box.

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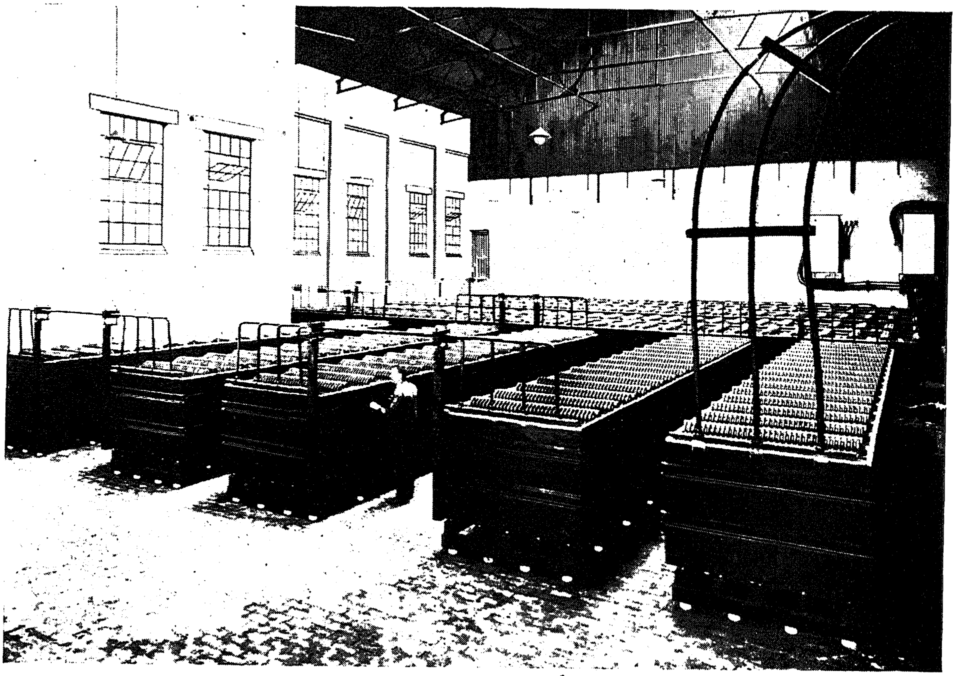
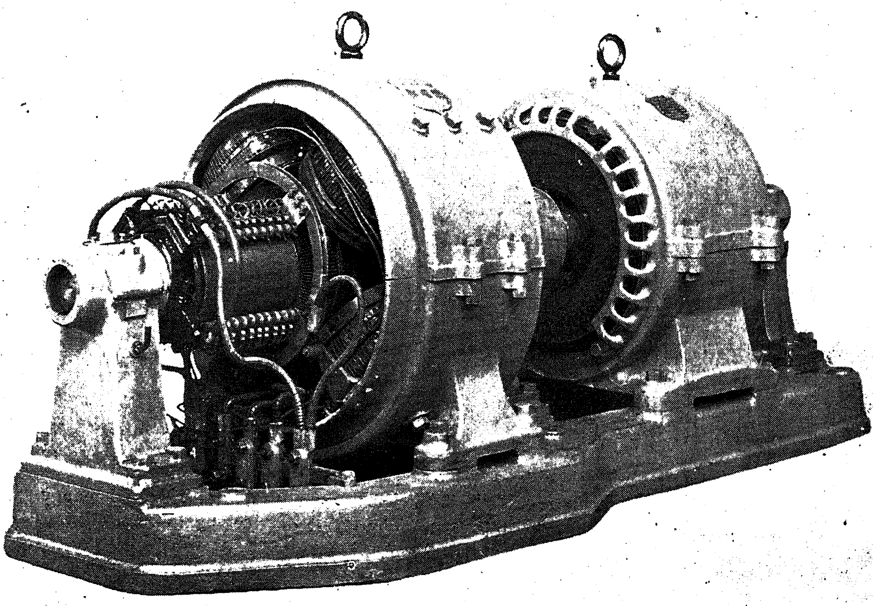


[By permission of the Chloride Electrical Storage Co.

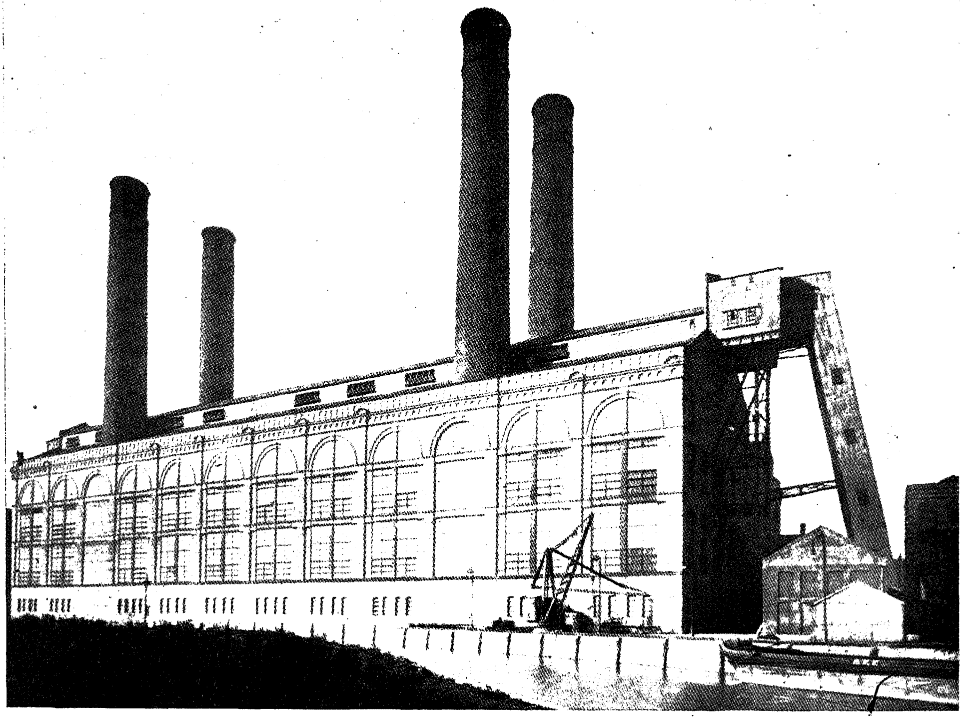
A Storage Battery or Accumulator as set up in Electric Supply Stations on the Direct-current System.



[By permission of the Lancashire Dynamo and Motor Co., Ltd.

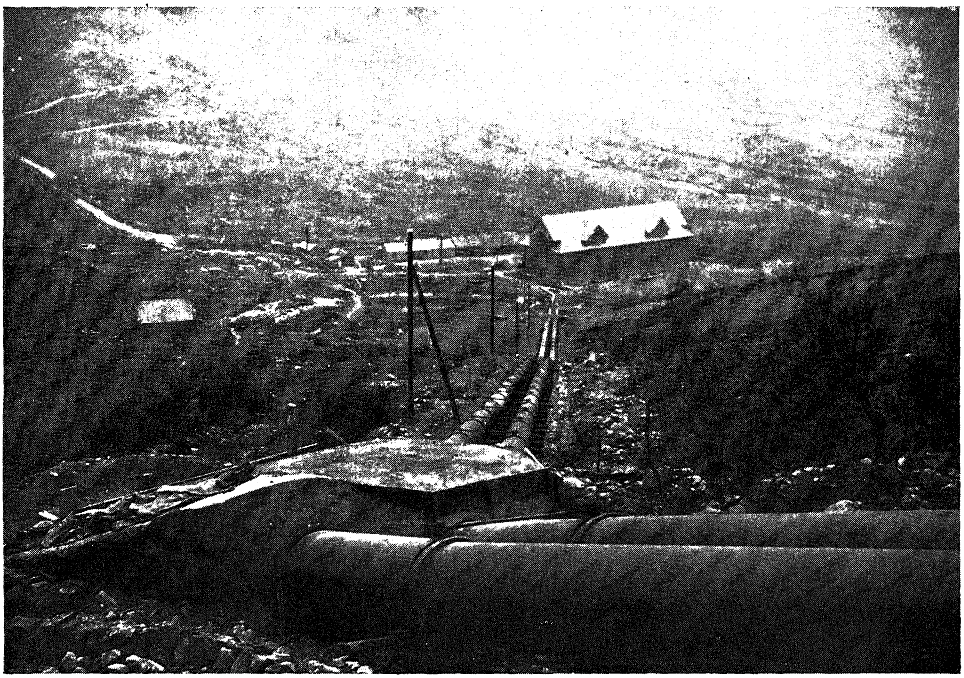
A Booster or Motor-driven Dynamo as used in Electric Supply Stations for charging the Storage Battery. The battery is used to store up energy during the hours of light load and give it out again at times of heavy load on the supply circuits.

PLATE 11.

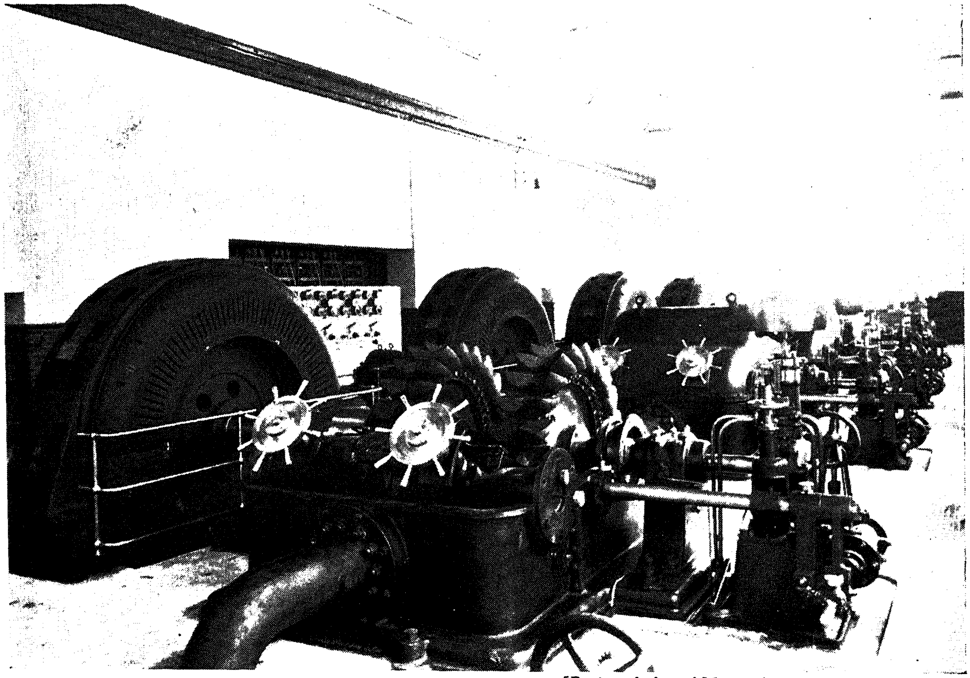


[*By permission of the Underground Electric Railways Co., Ltd.*

A View of the Exterior (upper diagram) and Interior (lower diagram) of the Lots Road Station, Chelsea, London, supplying electric power for Underground Co.'s Railways and Tramways in London. The alternators are three-phase and supply at 11,000 volts to sub-stations where there are rotary converters transforming the energy to direct current at 500 to 600 volts for traction.



[*By permission of Messrs. Bruce, Peebles & Co., Ltd.*



[*By permission of Messrs. Bruce, Peebles & Co., Ltd.*

A Generating Station of the North Wales Electric Power Co. The upper diagram shows the pipe line bringing water from Llyn Llydaw and Llyn Glaslyn which are high-level lakes on Snowdon, to the Power House. The lower diagram shows the interior of the power house at Cwm Dyli, Snowdon, North Wales. In the foreground one of the two water turbines has its outer case removed to show the blades which are revolved by the water jets. These drive alternators (at the back) giving electric current at 10,000 or 20,000 volts for distribution of power over North Wales, including that for the large Marconi Wireless Telegraph Station near Carnarvon.

[*To face page* 257.

posed of lead peroxide and the other wholly of spongy lead, the theoretical quantity capacity of these plates would be 50 ampere-hours.

In practice, however, owing to the weight of the inert lead backing, only from 6—8 ampere-hours per pound of both plates taken together is usually obtained, or even much less, depending on the type of plate.

The greater the proportion which the active material bears to the weight of the whole plate, the greater the capacity per pound. The attempt, however, to increase the capacity per pound beyond a certain point generally means the construction of a fragile and non-durable plate.

Edison has invented a storage cell which has some special properties. He uses nickel oxide and iron as the active materials, placed in a solution of 21 per cent. caustic potash in water. The positive plate consists of tubes made of nickel strip in spiral form, which are filled with nickel shreds and nickel hydroxide. The negative plate is a steel plate, with recesses or pockets in it filled with iron oxide (see Plate 9). The process of charging the cell by a current converts the green nickel hydroxide into black nickel peroxide, and reduces the iron oxide to the state of spongy iron, and on discharge the reverse actions take place. The cells are put up in steel boxes. They have a greater watt-hour energy capacity per pound of complete cell than a lead battery, and can give heavier currents for a given ampere-hour capacity without damage to the cell. They are much used for traction purposes.

Storage cells as used in supply stations consist of a glass box set on insulators. This box contains a number of positive lead peroxide plates sandwiched in between negative spongy lead plates, the plates not touching either each other or the bottom of the cell. Plates of the same kind are welded to heavy bars of lead, which connect them. A battery of cells comprises 110 cells for 220-volt supply, joined in series. Two or four such batteries are used in three-wire stations. The cells are filled up with dilute sulphuric acid of density 1·250 (see Plate 10).

To charge the cells we have to apply a gradually increasing E.M.F., from 2·0—2·5 volts per cell. Hence in a three-wire station in which the dynamos give 440—450 volts, and where there are 110 cells on each side of the middle wire, we have to supply an extra 55 volts E.M.F. on

each side to effect the charging. This is done by small dynamos, called "boosters," placed in series with each battery (see Plate 10, lower diagram).

By a certain type of booster invented by Messrs. Turnbull and McLeod it is possible to adjust the relative duty of the main dynamos and batteries so that the load on the engines is always kept constant and they are worked at their maximum efficiency. The batteries take up electric energy from the main dynamos at periods of light load and give it out to the supply circuits at heavy load, and so equalise the work.

It only remains to note that the ampere-hour capacity of a battery depends upon the rate of discharge, and is always stated as so many ampere-hours at a certain ampere delivery. One ton of storage cells can, as a whole, store up and deliver from 25—35 h.p.-hours of energy.

The second type of supply station is that furnishing electric energy in bulk for electric railways, urban tram service, and, perhaps, also lighting.

These stations are nearly always placed near a river, sea inlet or lake, so as to facilitate the delivery of coal and give water for steam condensation. In any case they are served by a railway siding.

The usual plan is to generate three-phase alternating current at a moderate pressure, say, 2,000—6,000 volts, and raise the voltage by transformers to 10,000—100,000 volts, transmit by underground or overhead cables, reduce pressure by step-down transformers, then apply the low-pressure three-phase current to drive induction motors, which are coupled directly to direct-current dynamos giving current at 450—550 volts, used for railway or tramway working.

Most of the large stations supplying electric current for electric railways in London, New York and other large cities are arranged as above described. The large station at Lots Road, Chelsea, which supplies the London Tube Railways, and that at Neasden, for the Metropolitan Railway, London, and the station at Greenwich belonging to the London County Council, are included in the above class. A view of the exterior and also the interior of the Lots Road Power Station is shown in Plate 11. The main building has a length of 453 feet, width 175 feet, and height 140 feet. There are four chimneys 275 feet high and 19 feet in internal

diameter. In the dynamo room there are eight steam turbine engines driving three-phase alternators, each of 6,000 kilowatt power, and two larger units of 15,000 kilowatt power, making in all ten units of 78,000 kilowatts, or about 100,000 h.p. These alternators supply current at 11,000 volts pressure and 33 frequency to twenty-seven transformer substations scattered about London, where the power is transformed to a direct current of 600 volts to feed the live rails of the tubes and electric railways, viz., the District Railway, Bakerloo, Hampstead, Piccadilly, City and South London Tubes and East London Railway, as well as the London United Tramways and Richmond Electric Supply Co. In addition to these urban stations there are many others in Great Britain supplying electric current for power on a large scale, such as the North Wales Power Co. (see Plate 12, page 257).

In about twenty years the world has been covered with immense power houses converting the potential energy of coal by means of steam engines, or else the potential energy of water at a high level into electric energy, which is transmitted to distant places up to 150 miles or more.

The design of the transmission lines and conductors has called for immense invention, guided by costly failures. In the case of long-distance transmission overhead or aerial conductors are used, made of bare copper or aluminium wire supported by porcelain insulators and carried on stout, tall wood posts or steel lattice towers according to the span.

The protection of these lines from lightning in tropical climates calls for elaborate devices. We have to lead the lightning discharge to earth without allowing the high potential of the line wires to start an electric arc. The nature of the devices varies with the voltage of the line. One kind much used in Switzerland consists of a pair of curved rods, like horns, which approach each other at the bottom, but spread wide apart at the top. One of these is connected to the line, and the other to the earth. If lightning strikes the line, it jumps across the narrow gap between the wires and goes to earth (see Fig. 6). If an alternating current arc is started by the line voltage, this rises up to the wide part of the gap owing to the tendency of the arc to lengthen itself, and then blows itself out.

As regards underground conductors, the type most largely used at

present is the armoured concentric cable. It is constructed with a core of twisted copper wires for one conductor. Over this is laid a somewhat flexible insulation, consisting of Manilla paper or jute saturated with resins and oils. Then another twisted layer of copper wires, more insulation, a third layer of copper wires and third insulation, and finally a lead sheath is pressed over the whole, perfectly watertight. A covering of jute or hemp is given, and then an armour of steel wires laid on with a twist and a final protective layer of hemp saturated with tar (see Plate 13, page 264).

At intervals joint boxes are put in to enable branches to be taken off. In soil likely to act on the lead such cables are laid in a wooden trough and filled in with pitch or bitumen.

The life of the cable is determined by the duration of the lead sheath, because as soon as that is pierced moisture enters and destroys the insulation.

In the case of long aerial lines worked at very high voltages there is an energy loss due to a glow discharge called the corona, which takes place through the air and causes the wires to appear luminous in the dark.

This effect has been much studied in the United States, where long high-voltage aerial lines are more used than in Great Britain or Europe (see Plate 14, page 264).

This chapter would be quite incomplete without reference to the magnificent progress made in the last thirty-five years in electric traction. It is now established on a sound engineering and commercial basis and, in fact, the concentration of population in large cities would be quite impossible but for the facilities electric traction affords in the construction of underground railways and urban surface rapid tram services.

The beginning of it dates from 1879, when at Berlin, Siemens and Halske built an experimental line in the Berlin Industrial Exhibition; and in 1880 Edison laid down an experimental line at Menlo Park, New Jersey, U.S.A. During the next few years in the United States Van Depoele, Leo Daft, E. H. Bentley and W. Knight built electric railways. The first really modern electric line was that equipped in 1887 at Richmond, U.S.A., by Mr. Frank J. Sprague, who has been a leading pioneer of electric traction. The success of this enterprise called the attention

of tramway managers all over the world to the advantages of electric over horse traction for urban railways, and it began to progress with giant strides.

Without detailing the various steps of progress in tramway working by electricity, we may say that the modern type of electric tramcar rests on a pair of bogies or trucks, and on each truck there is a series motor, which is geared with appropriate reduction gear to a pair of wheels. The series motor is used because it has a large starting torque, as it is called; that is, can exert the great effort necessary to start a loaded car in motion, even up an incline. At both ends of the car is an appliance, called a controller, with a handle, which the driver holds. On turning this handle over from stop to stop the following changes of connection take place: (1) the two motors are joined in series, with some resistance added; (2) the resistance is partly cut out; (3) the motors are joined in parallel, and (4) the resistance is entirely cut out. This gradually increases the power taken from the line, and starts the car from rest to full speed gradually. The electromotive force of the supply is generally 450—550 volts, and it must be direct current (see Plate 15, page 265).

There are two methods by which the current is supplied to the moving car: (1) the overhead or trolley system, and (2) the underground or conduit system. In the first a stout copper wire of hard drawn copper is suspended over the tramway line by poles and brackets. On the top of the car is an inclined sprit or rod, the upper end of which has on it a grooved metal block which is pressed up against the line by a spring at the base of the sprit. As the tram moves, the collector slides along the wire and picks up the current, which is sent to the controller by an insulated wire. The current returns to the dynamo by the railway lines, which are bonded together and connected by feeders to the station. The positive pole of the generator dynamo is connected by feeders to the overhead trolley line at various places, and the negative pole to the return or rail feeders.

In the conduit system, which is used in London and in large cities, an underground conduit is constructed along the track having a narrow slot opening into the roadway. In this conduit are placed two copper conductors supported on insulators. Between these conductors two

collecting plates on a plough slide, and these collector plates pass through the slot in the roadway and are attached to the underside of the car. The current is thus picked up by one collector of the plough as the car moves along, and, after doing its work, returns to the station *viâ* the other collector of the plough and return feeders.

Owing to the much larger size of car possible and to the rapid acceleration and greater economy of working, electric-worked cars rapidly replaced horse- and cable-worked tramways everywhere, and became in a short time the exclusive method of working urban tramways. It has, however, of late years found a serious rival in the petrol-driven motor omnibus, which is not tied down to a line, and can, therefore, make its way better through traffic and change its route if necessary.

Electric power began to be applied to the driving of trains on ordinary main line railroads about 1895, when a section of the Baltimore and Ohio Railway, U.S.A., was electrified. This was done for the sake of hauling trains through a long tunnel without smoke. Many of the other railways entering New York then followed this example.

The advantages of electric traction for certain purposes, such as haulage through long tunnels and underground urban railways, caused great attention to be given to the matter during the next ten years, with the result that several different systems have been evolved based on the use (1) of direct or continuous currents and (2) alternating currents, single or three-phase.

The standard system for underground, tube, or short urban railways is the low-pressure, direct current system. Alongside of the track or else between the running rails is placed a third insulated "live" rail which is kept 500—600 volts in electric pressure above the running rails. Along this live rail slip metal shoes which are attached to the motor coaches. These shoes pick up the current and it is returned to the running rails after passing through the driving motors and so back to the generators.

In underground railways, tubes and short electric lines the general usage is to equip two or more of the coaches with a pair of series motors just as in the case of electric tramcars. The controllers of all these motor coaches are connected electrically to a master controller placed in a

driver's cab at one end of the train. The train is then driven not merely by power applied to one or two axles, as in a steam locomotive, but by electric power applied to half a dozen or more axles. This system, due to Mr. Frank J. Sprague, is called the multiple unit system of working. The driver's cab also contains motors and pumps for the supply of compressed air for the brakes.

Another precaution against accident is the arrangement called the "Dead Man's handle."

As long as the driver has a grip of the handle of the master controller a circuit is closed which transmits current from the "live rail" to the motors. If, however, the driver were to faint or die at his post the release of his grip would open a circuit which would cut off the current and the train would gradually be brought to rest.

The direct current at 450—550 volts for the supply of energy to the motors is generally given by rotary converters at sub-stations, and the energy is conveyed to these stations from the main generating station in the form of a three-phase alternating current. This is the mode of working the Central London Electric Railway, the so-called "Tube," also the Metropolitan and Metropolitan District Railways in London.

A large generating station at Neasden, near Harrow, supplies the electric power for the Metropolitan Railway in London, and another at Lots Road, Chelsea, already described, that for the Tubes and the District Railway. This last station supplies current for some seventy miles of railway in all, operating 200 or 300 trains at the time of heaviest load, and each train takes about 130 h.p. on an average (see Plate 11, page 257).

In the case of trains on main line railways, where the train has to be made up with the ordinary coaches which may be drawn for certain distances by a steam locomotive and then through a tunnel, as for instance, the Simplon tunnel, Switzerland, or on the New York Central Railway, the Pennsylvania Railway, or the New York, New Haven and Hartford Railway, which all enter New York through long tunnels, then it is necessary to concentrate the electric driving power on one vehicle, called an electric locomotive (see Plate 16, page 265).

When large amounts of power have to be collected off a trolley line or third rail, it is better to reduce the current and increase the voltage, and

accordingly voltages up to 1,200 volts for direct current working have been employed. In his excellent book on electric trains, Mr. H. M. Hobart, one of our leading authorities on electric traction, gives a list of eleven railway lines in the United States where the 1,200 volt direct-current system is employed. Owing to the great advantages the alternating current possesses in ease of transformation, it has been much used in certain classes of electric railway working. In this case either three-phase or single-phase motors can be employed. A large amount of railway traction work has been done in Switzerland and Italy with three-phase currents and three-phase induction motors. These motors have the advantage of light weight per horse-power, but they have the disadvantage that they run at nearly the same speed at all loads. Hence they impose an augmented output on the generating station when the train is going uphill.

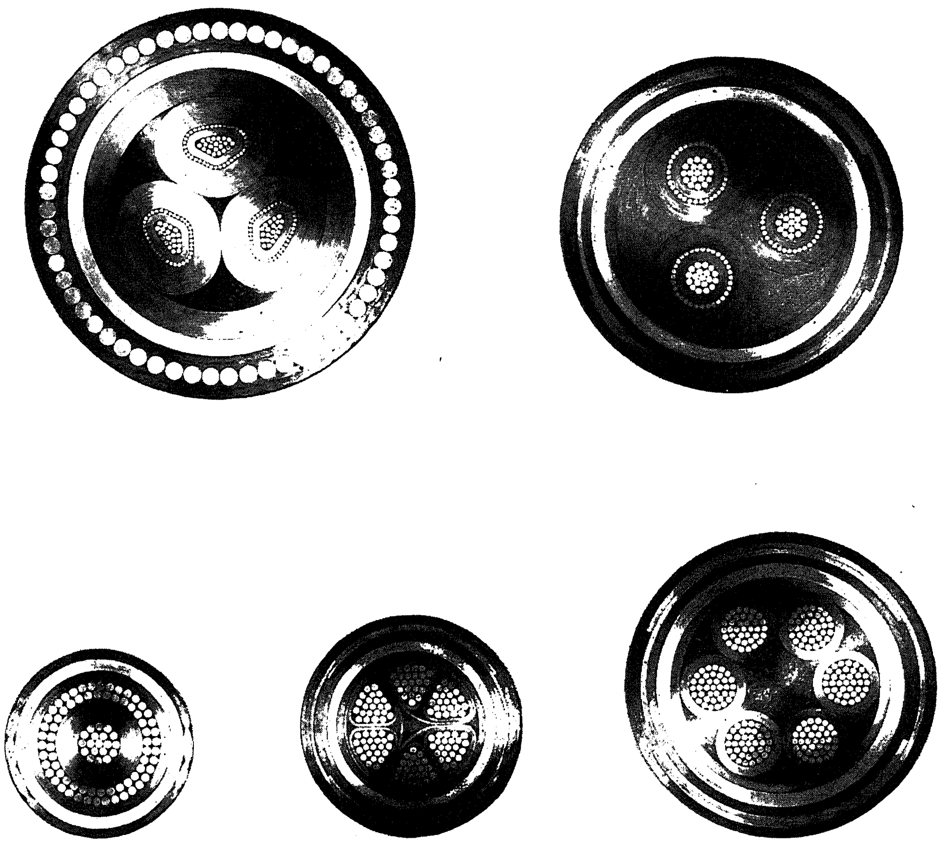
The three-phase railway requires two trolley wires, and the running rails are employed as the third wire. Single-phase alternating current motors have also been used to a large extent on electric railway work. This type of motor is, however, larger, heavier, and more expensive than a direct current motor of equal horse-power. The great advantage of single-phase work is that the current can be transmitted at high voltage and taken up even at a pressure of several thousand volts from the trolley wire or third rail and then transformed to a lower pressure for the motor by static transformers on board the locomotive.

Great controversies have arisen as to the relative merits of this system and direct current. For short line railways with a rapid service and frequent stops the direct-current system has unquestionable advantages in lower cost of working and equipment.

For the electrification of long main line railways some form of alternating current will doubtless have to be employed. The single-phase system has been adopted on that portion of the London, Brighton and South Coast Railway called the South London Elevated Railway, which has already been electrified near London, doubtless with a view to the ultimate adoption of electric working on the whole of the London and Brighton line.

The same single-phase system using a trolley pressure of 6,600 volts

PLATE 13.



[*By permission of Messrs. Siemens Bros., Ltd.*

Sections of Armoured Cables used for the conveyance of Electric Current underground. They consist of stranded copper wire cables insulated with resinous material (paper or hemp) and included in a lead tube or sheath which is then protected by steel wires or tape called the armour. The cables are laid directly in the earth.

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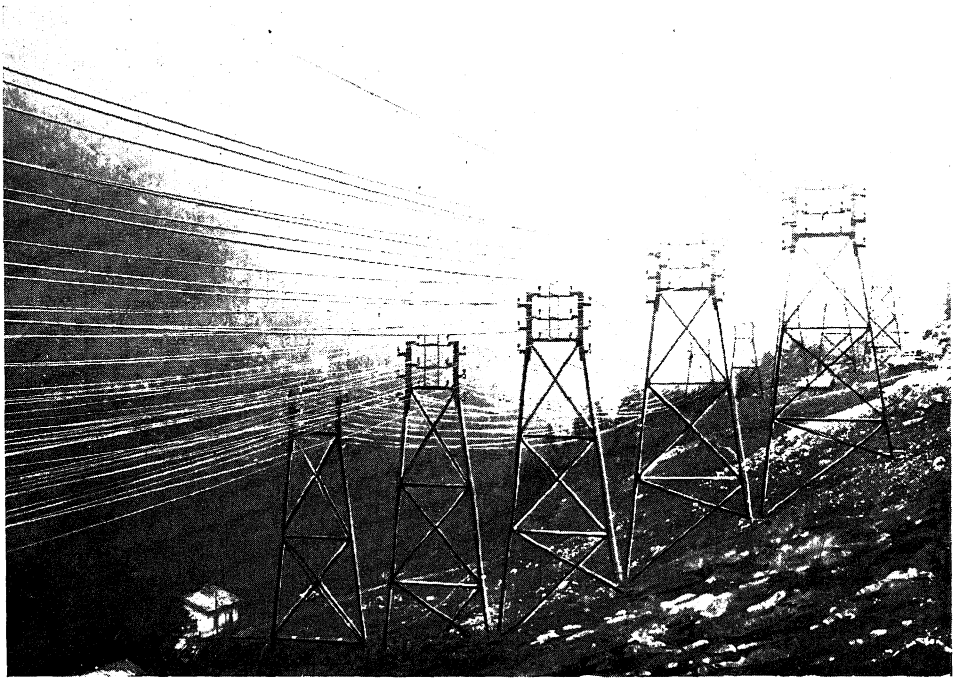
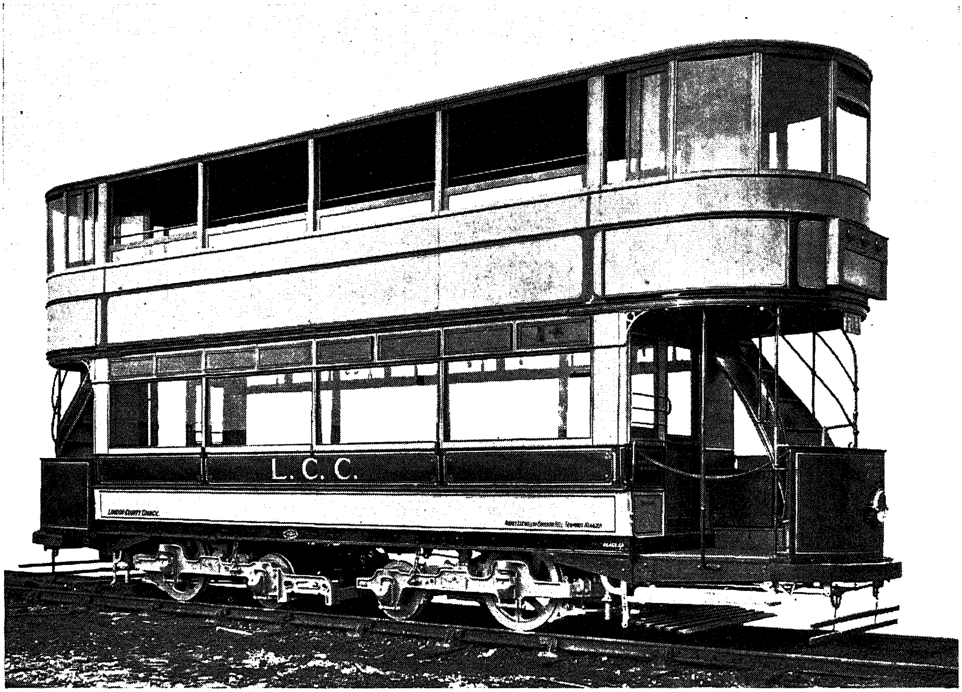
PLATE 14.



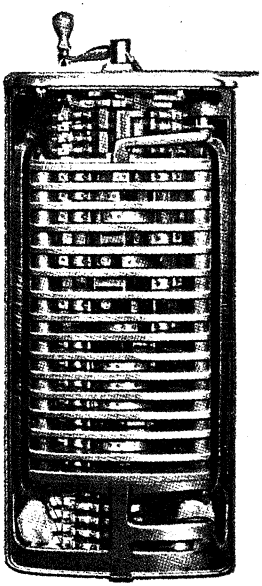
[*By permission of the British Aluminium Co., Ltd.*

Overhead Cables of one of the largest Power Transmission Schemes in the World. Constructed with twenty three-phase circuits carrying over 150,000 kilowatts of power or nearly 200,000 h.p. at a pressure of 10,000 volts. The conductors are of aluminium.

PLATE 15.



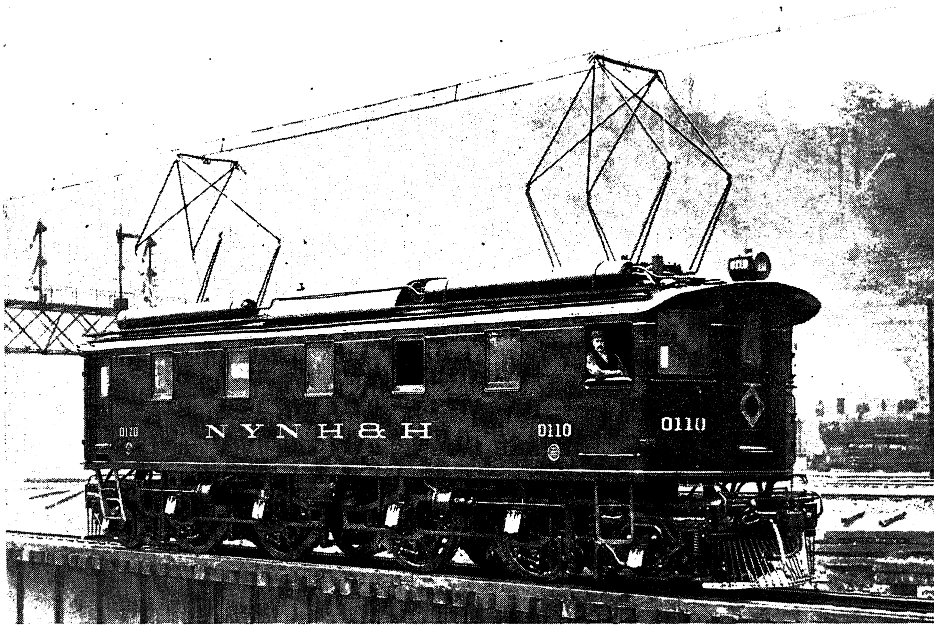
[*By permission of Messrs. Hurst, Nelson, Ltd.*

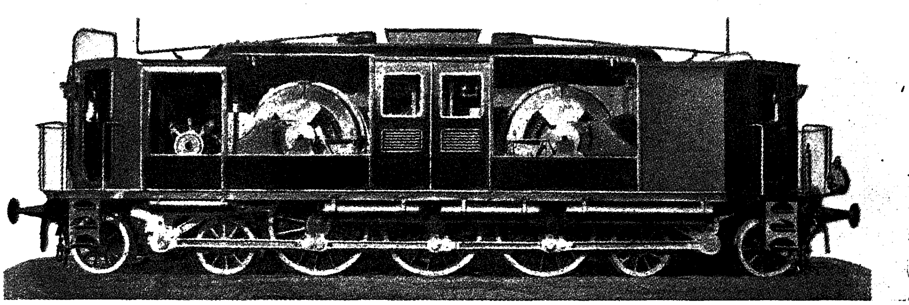


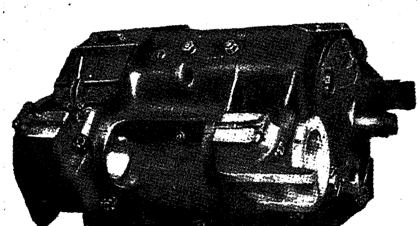
A London County Council Electric Tramcar working on both the Conduit and Overhead systems. Underneath the car is the "plough" which projects into the slot in the roadway and picks up the current. The electric motors are attached to the wheel trucks on which the car runs. To the left is shown a section view of the controller at each end of the car.

By permission of the Metropolitan Vickers Electrical Co.

PLATE 16.







The upper view shows a 110-ton Electric Locomotive operating on the New York, New Haven and Hartford Railroad, U.S.A. It is equipped with four Westinghouse 340 h.p. single-phase alternating current electric motors working at 25 cycles per second. Current is taken at 11,000 volts. The rectangular rods on the top are the collectors which pick up the current from the overhead lines. The two lower views show a section of an electric locomotive and an electric motor.

[*To face page* 265.

and a frequency of 25 cycles has been adopted on the Heysham, Morecambe and Lancaster branch of the Midland Railway, England.

The weight of the motors used per horse-power exerted has been reduced somewhat by overloading the motor but keeping it cool by a forced draught of air.

Finally, we may say that the practical working of railways by electric power is a complete engineering success, but the questions yet remaining to be considered are the financial aspects for main line working as compared with steam locomotives. The Engineers of all main line railways are now giving close attention to the subject of electric working. Considerable suburban sections of such lines as the London and North Western Railway, Midland Railway, North Eastern Railway, and London and Brighton Railway in England have been electrified.

For suburban traffic where stops are frequent and high speed must be kept up between stations the more rapid acceleration of an electric train gives it an advantage over the steam locomotive.

In Switzerland the success of the electric working of many sections of the railways, such as the Simplon tunnel and the many electric mountain railways, has led to the consideration of the problem of electrifying all the railways in that country. In North Italy much electric railway work has been done.

The question of coal cost, transport, and storage, and also the comfort of working of electric trains for the staff, is compelling all railway authorities to study the subject of electrification, and even if long main line railways are not yet so worked, every year will see an addition to the electric operation of those sections near large towns where vast numbers of workers have to be carried morning and night to and from their daily work.

CHAPTER VI

ELECTRIC THEORY AND MEASUREMENTS

THE great development in the technical applications of electricity during the last fifty years has been accompanied by a largely increased insight into the nature of this physical agency, and by power to measure accurately its effects and properties, due to purely scientific investigations. The early submarine cable and telegraph work had shown the importance of being able to measure certain electric quantities in appropriate units, and accordingly Lord Kelvin (then Professor William Thomson) had suggested, as far back as 1861, the appointment of a committee of the British Association to consider this question. This committee continued its valuable work, with an interval between 1870 and 1881, up to 1913, when it was dissolved.

One of the earliest requirements in practical telegraphy was a means of measuring electric resistance and a unit in which to state the results. A conductor through which an electric current flows dissipates some of the energy of the current as heat, and the quality of the conductor, in virtue of which it does this, is called its electric resistance. The electric resistance of a piece of wire varies as the length, inversely as the sectional area, and is proportional to a special quality of the material called its specific resistance. It was found in early days of cable work that various samples of copper wire differed very much in specific resistance.

The B.A. Committee decided that all their electric units should be based upon a metric system of measurement in which the centimetre is the unit of length, the gram the unit of mass, and the second the unit of time. It is called the C.G.S. system. On this system a unit velocity is a speed of 1 centimetre per second, and a unit of force one which gives to a mass of 1 gram a velocity of 1 centimetre per second after acting on it for one second. This unit force is called 1 dyne. The force with which the earth attracts a mass of 1 gram, or what is commonly called its weight, is

nearly 980 dynes. The unit of work is done when a mass is moved for 1 centimetre against a force of 1 dyne. This is called 1 erg. The rate of doing work is called power, and the unit of power is 1 erg per second. These units are too small for many purposes, so multiples of them are used. Ten million ergs is called 1 joule, and a power equal to 1 joule per second is called 1 watt. 746 watts are equivalent to one, so-called, horse-power.

The fundamental electrical quantities which require measurement are electric current, resistance, potential capacity, and inductance.

It has been agreed that the names of the practical units shall be derived from those of celebrated physicists, and hence the unit of current is the *ampere*, called after M. Ampère, the French scientist. The unit of resistance is the *ohm*, called after Dr. G. S. Ohm, a German physicist. The unit of potential difference is the *volt*, after Volta, the Italian philosopher, who first gave us the means of creating a current by a battery. The unit of electric capacity is called a *farad*, after Faraday, and the unit of inductance a *henry*, after Joseph Henry, his contemporary in the United States. These electrical units are related to the mechanical units in the following manner. It is well known that when two wires placed parallel to each other are both traversed by electric currents in the same direction the circuits attract each other. This attraction, other things being equal, is proportional to the product of the strengths of the currents in the two wires. If then the same current is made to flow through both the wires, by joining them in series the attraction is proportional to the square of the strength of the current. Hence, if the current is doubled the attraction is four times what it was before, and if the current is increased threefold the attraction becomes nine times. If, then, a coil of insulated wire is suspended from one arm of a pair of scales and underneath it placed another coil of similar kind, and if one and the same electric current is made to flow through both coils in the same direction, they will pull each other together, and it will seem as if the coil on the scale pan became heavier. This apparent increase in weight can be balanced by a weight put in the other scale pan, and we can thus measure the attraction of the coils in dynes, because every gram weight placed in the counter-balance represents 980 dynes.

If the coils have known and measured sizes and number of turns, it is possible to calculate the attraction due to a current of 1 ampere flowing in each coil or conversely from the measured attraction to determine the current flowing through the wire in amperes. In this way we can construct an absolute ampere balance (see Fig. 1) for weighing electric currents. A current-weigher of this type was designed for the National Physical Laboratory, Teddington, in 1898, by the late Professors Ayrton and Viriamu Jones. Having determined the unit current or ampere we can determine our unit of resistance. If we pass a known current in amperes through a wire and observe the *rate* of production of heat in it, measured in *watts*, we know from Joule's law that the quotient of the square of the current in amperes by the power dissipation in watts is the resistance of the wire in ohms. Hence, we can manufacture a coil of wire which shall have a resistance of 1 ohm. Such coils are called standard ohms. Finally, if we pass a steady, direct current of 1 ampere through a wire having a resistance of 1 ohm, the potential difference or electric pressure between the ends of the wire will be a volt. This follows from the well-known law of Ohm, enunciated first in 1827, which states that the current in a circuit not containing any source of electromotive force is proportional to the difference of potential between the ends and inversely as the resistance.

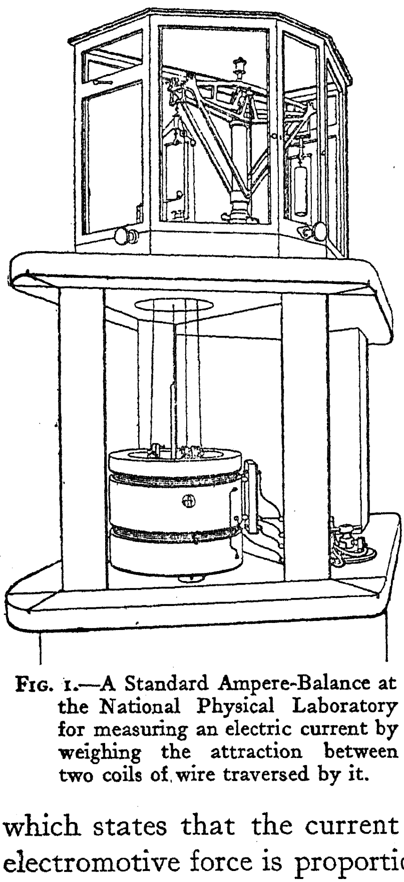


Fig. 1.—A Standard Ampere-Balance at the National Physical Laboratory for measuring an electric current by weighing the attraction between two coils of wire traversed by it.

If we are dealing with a circuit which includes such a source, say, a voltaic battery, then this possesses a certain power of creating a current which is called its electromotive force, denoted by E.M.F. or simply by the letter E. The current produced in a circuit having resistance, which

must include that of the voltaic cell itself, is proportional to this E.M.F. and inversely as the total resistance. The meaning of the above statements may be made clearer by comparing the motion of electricity, which we call an electric current, with the motion of water in a pipe. The pipe offers a certain obstruction to the flow of water through it which may be compared with the electrical resistance of a wire. If we connect this pipe to an elevated cistern of water, the water will flow down in consequence of the pressure due to the *head* of water. Difference of level in the case of water flow corresponds to difference of potential in the case of electricity flow, and to difference of temperature in the case of heat flow. On the other hand, water may be made to flow through a pipe by the action of a pump, and a voltaic cell is in effect an electric pump setting electricity in motion through wires, just as a water pump moves water through pipes.

Prior to 1870 much progress had been made in devising means for measuring these electrical quantities. The British Association Committee had arranged the above described system of units, and eminent members of that committee, viz., Professors James Clerk Maxwell, Balfour Stewart and Fleeming Jenkin, working at King's College, London, in 1862–63, with an apparatus designed by Lord Kelvin, had determined the resistance of a certain coil of wire in ohms and embodied their results in the form of standard coils of wire made of various alloys which were called the British Association (B.A.) standards of resistance.

Long before that time Sir Charles Wheatstone had re-invented in 1843 an instrument originally devised by Mr. S. Hunter Christie in 1833 for comparing electric resistances which has since always been called a "Wheatstone's bridge." This arrangement is as follows: Let four wires whose relative resistances have to be determined be arranged and joined together in a lozenge shape (see Fig. 2), and let one pair of opposite corners be connected to a battery of voltaic cells and the other pair to a sensitive mirror galvanometer (see Chapter I.). If we adjust the resistances of these four coils, which we shall denote by the letters P, Q, R, S, so that they are in continued proportion, viz.,

$$P : Q = R : S$$

then the galvanometer will indicate no current when the battery is placed

as described. If, then, we know the value of three of these resistances the fourth can be calculated. In practice this is achieved by so-called plug resistance boxes. A number of coils of silk-covered wire are prepared of manganin, an alloy of manganese, copper, and nickel, which has the property of not increasing in its resistance with rise of temperature like other metals. These coils are adjusted to definite values in ohms. On the ebonite slab which forms the top of a box are arranged a number of brass blocks, which can be connected by metal plugs put in between them (see Plate 1, page 272, top diagram).

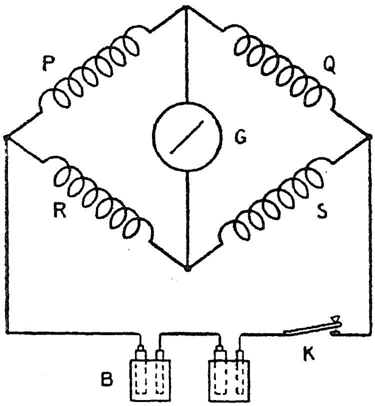


FIG. 2.—The arrangement of four Resistance Coils P, Q, R, S, called a "Wheatstone's Bridge." B is the battery supplying current, K is a contact key and G is a galvanometer.

The coils of wire are placed in the box and their ends joined to the blocks, so that, when a plug is taken out of a hole, it leaves two adjacent blocks connected by the wire, but when it is put back it "short circuits" the coil. The coils are arranged in two sets of 1,000, 100, 10, 1, and 1, 10, 100, 1,000 ohms, which are called the ratio arms of the bridge, and correspond to the resistances P and Q above. The other set of coils, called the measuring arm, is composed of 1, 2, 3, 4, 10, 20, 30, 40, etc., ohm coils.

The resistance to be measured is joined to two terminals, and the battery and galvanometer to two other pairs. We first adjust the ratio arms to have any given ratio, say, 10 : 1, and then the measuring arm is varied by taking out plugs, until the galvanometer indicates no current. Thus, suppose we have $P = 100$, $Q = 10$, and S is found to be 43 ohms, then the resistance of the circuit being measured is 430 ohms, because $P : Q = R : S = 100 : 10 = 430 : 43$.

The chief measurements required in telegraphy are those of resistance and capacity, but as soon as large dynamos were constructed, in or about 1870, and especially as soon as public electric lighting began to be undertaken, the important measurements were those of current, voltage, quantity, and power. Instruments for this purpose are called ammeters,

voltmeters, ampere-hour meters and wattmeters. Hence, soon after 1882 many inventors endeavoured to supply simple portable instruments with scales divided to indicate, by the pointing of a needle, the value of a current in amperes of a voltage in volts. The later Professors Ayrton and Perry were early in the field as inventors of such instruments, and Messrs. Crompton and Kapp designed others of a different type.

The principle on which many instruments in early days operated was as follows :—If a current is sent through a spiral coil of wire, it creates in the interior of the helix a magnetic field. A small rod or mass of iron, when placed in a non-uniform magnetic field, tries to move from places where the field is weak to places where it is strong. This effort on the part of the iron can be resisted by a spring or by a weight, and the displacement of the iron indicated by an index needle moving over a scale of degrees. The stronger the current, the stronger the field and the greater the displacement. Hence the scale of the instrument can be graduated to read currents in amperes directly (see Fig. 3).

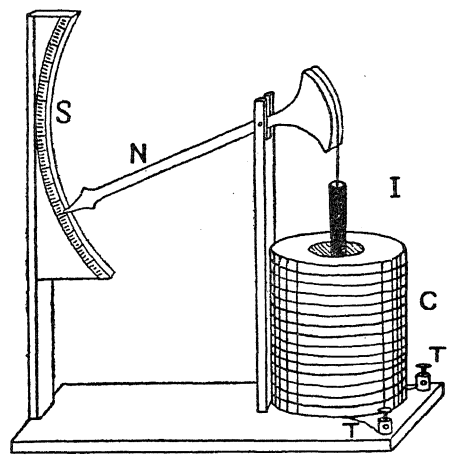


FIG. 3.—A simple form of Ampere or Current Meter. C is a coil of insulated wire, I is an iron rod which is sucked into the central aperture of the helix when a current passes through it to an extent which measures the current. The scale S over which the indicating needle N moves can be graduated to read directly in amperes or units of electric current.

In the case of an ammeter the coil of wire is made to have as low a resistance as possible. If the coil has a very high resistance, say, several hundred ohms, then the current which flows through it is proportional to the voltage applied to the ends. The instrument then becomes a voltmeter, and can be calibrated to read in volts.

Many kinds of ammeters and voltmeters were at one time in use which, in one way or another, operated by the movement of a mass of iron in the field of a coil of wire when an electric current was passed through it ; but this type of instrument had several defects.

Another instrument, called a portable dynamometer, was devised about 1882, which depended on the fact that when a coil of wire which is suspended so as to be free to rotate is placed near to another fixed coil and the two coils are traversed by the same electric current the movable coil tends to turn so as to place its axis in line with that of the other. This movement is resisted by the torsion of a spiral spring, and when the current passes, the top of this spring can be twisted so as to

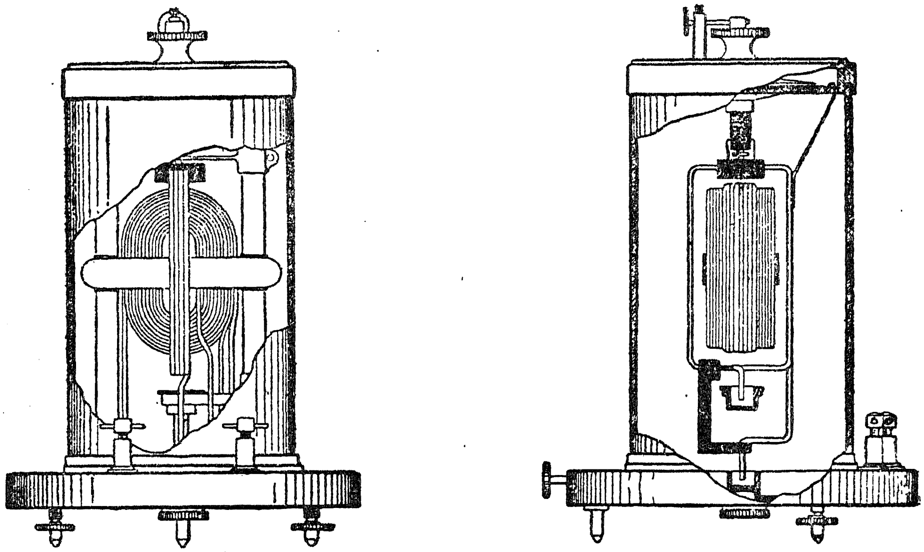
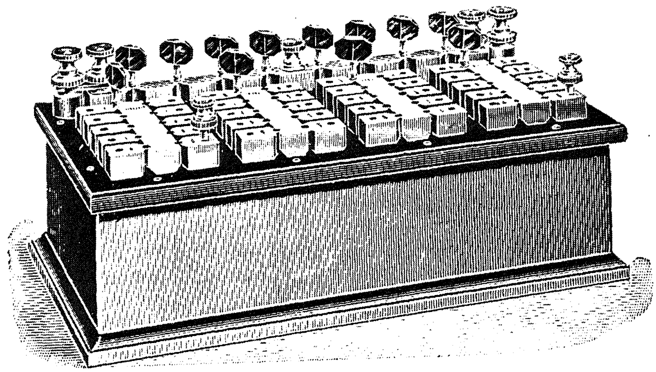


FIG. 4.—An Electro-dynamometer for measuring Electric Currents. In this instrument there is a fixed rectangular coil of insulated wire and another coil freely suspended by a spiral spring with its plane at right angles to that of the first. The current flows in series through both coils and is led into and out of the movable coil by means of cups full of mercury in which the ends dip.

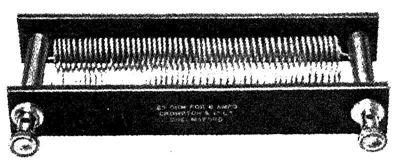
bring the coils back to their original position, in which the axes are at right angles to each other. The instrument is not generally direct reading, but has a scale of degrees by which to measure the twist given to the head of the torsion spring, and from a table supplied with the instrument the operator can find out the corresponding current in amperes (see Fig. 4).

As soon as instruments of the above kind began to be made, the question of calibrating them accurately became pressing.

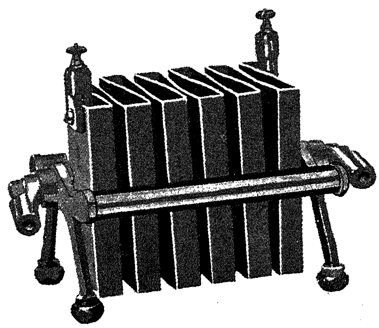
PLATE I.



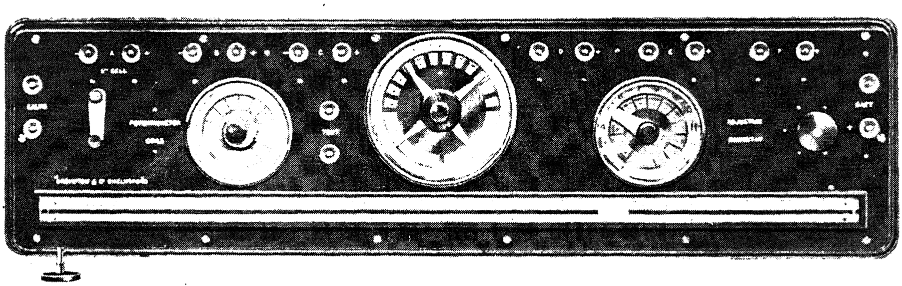
A Plug Pattern of Wheatstone's Bridge for measuring Electrical Resistance.
(See page 270.)



A Standard Resistance Coil. (See page 277.)



A Standard of Low Resistance. (See page 277.)



A Crompton Potentiometer for measuring Electric Current and Voltage. (See page 277.)

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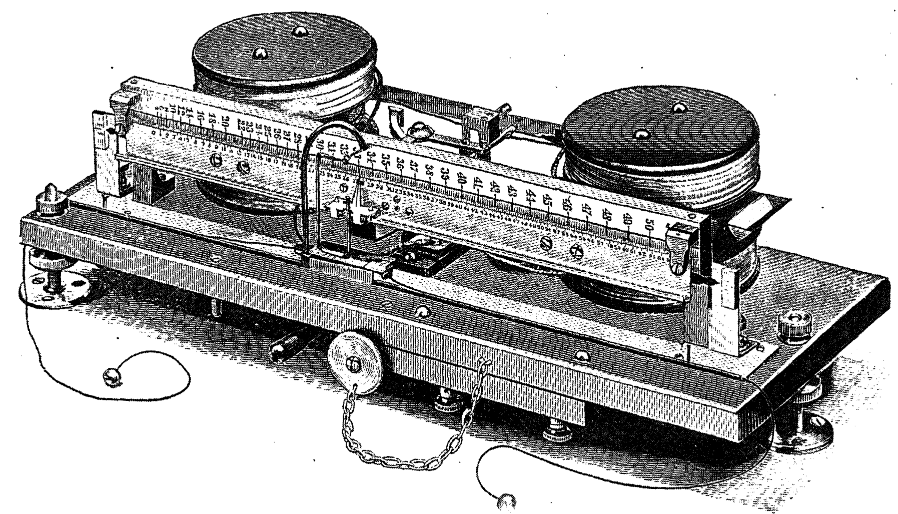
PLATE 2.



A Kelvin Ampere Balance for weighing Electric Currents. The balancing weight is pulled along a tray attached to the movable arm of the balance by a silk cord until the equilibrium is established.

[*To face page* 273

An accurate but rather tedious method of doing this is by the electro-deposition of silver or copper. If we place in a solution of sulphate of copper (blue vitriol) a pair of clean copper plates and pass an electric current from one plate to the other through the solution (called the electrolyte), the current dissolves copper off the plate by which it enters and deposits an equal weight on the plate by which it leaves the solution. Or we may employ a solution of nitrate of silver (luna caustic) and two silver plates. Faraday showed that there is an exact relation between the strength of the current and the amount of metal removed or deposited.

By the employment of a standard ampere balance placed in series with such an electrolytic cell or voltameter, as it is called, many physicists, chiefly the late Lord Rayleigh, have shown that in a silver voltameter a current of 1 ampere deposits in one second 0·001118 gram of silver, or 4·025 grams of silver per hour. In the case of copper the ampere deposits 1·177 grams per hour. In fact, the ampere is now legally defined by international agreement in terms of the silver deposited by it as above stated. It would, however, be a very laborious operation to calibrate completely the scale of an ammeter, especially if intended to read very large or very small currents by silver or copper deposit. The author, therefore, gave careful thought to the subject in and about 1883, and arranged a method, which is most easily employed, depending on the use of an instrument called the potentiometer, but which the present writer modified so as to simplify greatly its application for this purpose.

If we stretch a long uniform wire PQ over a scale and send through it a steady current from a voltaic battery B, there will be, as already explained, a fall in electric potential along the wire, just as in the case of a water or gas pipe there is a fall of pressure along the pipe (see Fig. 5).

Suppose we connect to the positive end of this wire two other wires terminating in sliding contacts which can be moved along the stretched wire (see Fig. 5) and insert in the circuit of each of these two wires instruments G, G called galvanometers, for detecting the presence of an electric current, then it is obvious that the current flowing down the stretched wire will partly be diverted through the two by-pass circuits.

In the next place let us insert in each of these side circuits two different voltaic cells B_1, B_2 or other sources of electromotive force, so placed that

their E.M.F. tends to oppose the current flowing through the circuits which comes from the main wire. It is then possible to move the sliding contacts until the fall in potential from the slider to the negative end of the main wire just balances the E.M.F. of the inserted cell, and hence the galvanometer in the side circuit indicates no current. The E.M.F. of the cell is then proportional to the length P*a* or P*b* of the slide wire between the slider and the positive end of the wire.

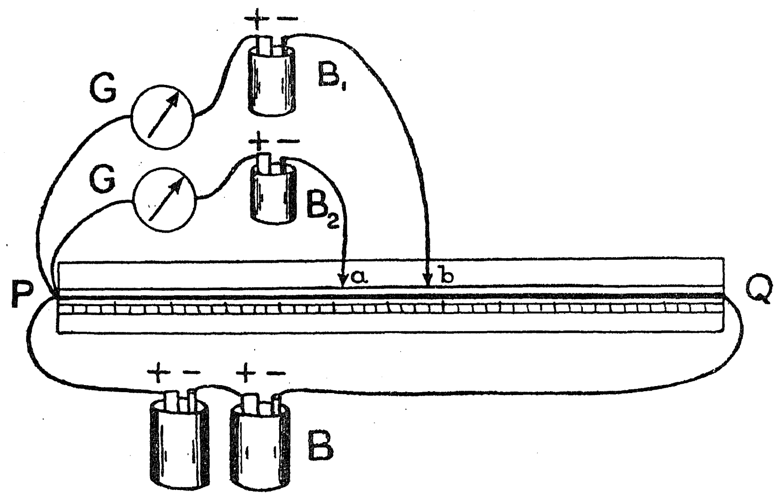


FIG. 5.—The arrangement known as a Potentiometer. PQ is a wire along which a battery B sends a current. The fall of potential down this wire for a given length P*a* or P*b* is balanced against the E.M.F. of a cell B_1 or B_2 and serves to measure it. The balancing point is determined by the position of the slider *a* or *b* when the galvanometer G indicates no current.

We can thus obtain the ratio of the E.M.F. of the two voltaic cells, because they are in the ratio of the two lengths of the slide wire.

This arrangement is called a *potentiometer*, and it was devised by Poggendorff in 1841.

In 1882 the author felt the want of some arrangement to enable him to measure quickly and accurately the current and voltage of incandescent lamps, and modified the above-described potentiometer into a direct reading instrument for that purpose as follows :—

In 1873 Mr. Latimer Clark invented a form of voltaic cell, since called

a Clark Standard Cell, which gave a very constant E.M.F. as long as it was not allowed to send much current. The cell consisted of a glass vessel in which there was some mercury, and over this a paste made of mercurous sulphate and zinc sulphate, and in that a zinc rod. Connections were made to the mercury and the zinc by platinum wires (see Fig. 6). The E.M.F. at 16° C. is 1·434 volts.

Dr. A. Muirhead and also the late Lord Rayleigh improved the con-

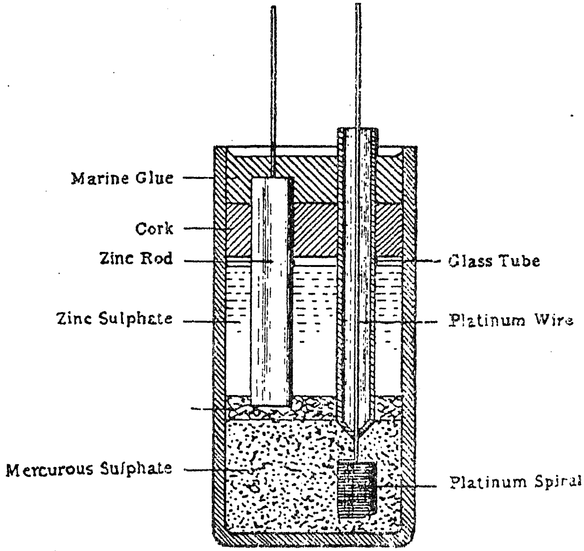


FIG. 6.—A Standard Voltaic Cell called a Clark Cell which gives a constant E.M.F. at fixed temperatures.

struction of the cell, and its constancy and E.M.F. was investigated by numerous physicists.

The author designed a standard cell in 1885 consisting of a zinc rod placed in a solution of zinc sulphate, and a copper rod in copper sulphate, the two solutions having certain concentrations according to prescription, and these liquids were placed in the two sides of a U-shaped tube which formed the battery cell.

The E.M.F., when made according to certain rules, is 1·072 volts. Mr. Weston designed later on a standard cell in which cadmium and

cadmium sulphate replace the zinc and zinc sulphate of the Clark cell. This Weston cell has less variation of E.M.F. with temperature than the Clark cell. It has an E.M.F. at 20° C. of 1·0186 volts. The author's improvement in the potentiometer consisted in making it direct-reading, as follows:—

The wire, called the slide-wire, on which the sliders move, is stretched on a board, and under it is a scale divided into 2,000 parts. The ends of this wire AD are connected through a variable resistance with a single storage cell B having an E.M.F. of a little more than 2 volts (see Fig. 7).

To one end of the slide wire the end of another by-pass wire is attached, and the second end of this last wire is connected to the slider. In the by-pass wire is inserted a galvanometer G for detecting a feeble electric current and a switching arrangement, by which either a Clark cell C_1 or other standard cell can be inserted in the by-pass circuit, or else some other source of E.M.F. This E.M.F. must be in such a direction as to oppose the current, through the by-pass wire, which would flow if the E.M.F. were not inserted. We begin operations by inserting the Clark cell, which we shall assume has a temperature of 16° C. and an E.M.F. of 1·434 volts. We then place the slider on the slide wire at 1,434 divisions from the end, and alter the current in the slide wire by the resistance until the galvanometer in the by-pass circuit shows no current. We then know that the fall of potential in the slide wire down 1,434 divisions is 1·434 volts (see Fig. 7).

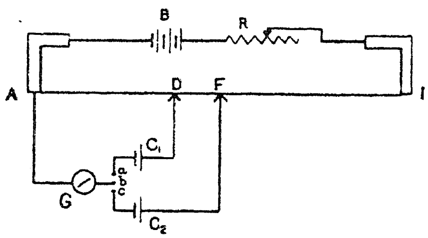


FIG. 7.—The Scheme of Connections for a Direct-reading Potentiometer (Fleming). AI is the stretched wire which is a bare eureka wire. B is a storage cell and R a variable resistance. G is the galvanometer, C_1 is a Clark cell and C_2 a cell of which the E.M.F. is to be determined. The E.M.F. of C_1 is to that of C_2 as the length AD is to the length AF on the potentiometer wire when the galvanometer indicates no current.

Suppose we then require the E.M.F. of some other cell C_2. We insert it in the by-pass circuit in place of the Clark cell and find the position of the slider to bring the galvanometer (commonly called the galvo) to zero. Suppose the slider must be at 1,800 divisions, we then know that this E.M.F. is 1·8 volts.

To use this direct-reading potentiometer to measure currents we have

to provide a set of strips of manganin which have known low resistances, say, 1 ohm, 0·1 ohm or 0·01 ohm. We pass the current to be measured through these strips and from the ends of the strip we take potential wires which can be connected across the gap in the by-pass circuit of the potentiometer, and so we can measure the fall in potential down the strip when a current is flowing through it (see Plate 1, page 272).

Suppose, for instance, we use the 0·01 ohm strip and find that there is a voltage drop or fall of potential down it of 1·72 volts when a steady current flows through it. Then this current, measured in amperes, is by Ohm's law the quotient of 1·72 by 0·01, or is 172 amperes.

We can also use the potentiometer to measure a high voltage as

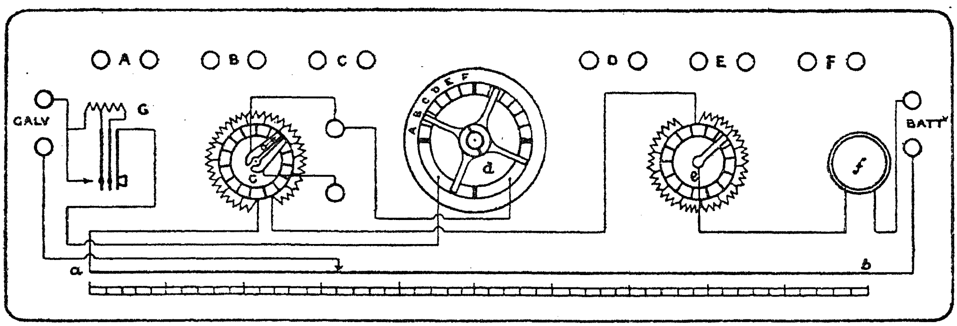


Fig. 8.—Scheme of Connections of a Crompton Potentiometer. The instrument is only a rather more elaborate arrangement of circuits similar to that shown in Fig. 7.

follows: We provide a very high resistance in the form of a long wire which is divided into two sections, one having, say, one-hundredth the resistance of the whole wire. If we then connect the ends of this high resistance to the points between which we desire to know the voltage, we shall also know that the potential fall down the small section of that wire is one-hundredth of the fall down the whole wire. If, therefore, we bring potential wires from the ends of the smaller section of this resistance (called a divided resistance) to the potentiometer we can measure the volt drop down the one-hundredth part of it and hence calculate that the total fall in potential is one hundred times as great.

This method of measuring currents and voltages by the potentiometer is extremely convenient, because the instrument itself may be a long way

from the place where the actual currents and voltages to be measured exist.

The potentiometer is only connected with that locality by fine wires in which no currents exist at the moment of making the measurement. The author was the first to put this method into practice in electro-technical measurements, and to make the potentiometer direct reading by "setting" it by a Clark or other standard cell. The writer designed in 1885 for Messrs. Crompton & Co., at their Chelmsford works, a potentiometer arrangement of this kind for calibrating ammeters and voltmeters, and Colonel R. E. B. Crompton devised neat and compact potentiometers on the same plan which have been extensively used in electrical works and factories (see Fig. 8 and Plate 1, page 272).

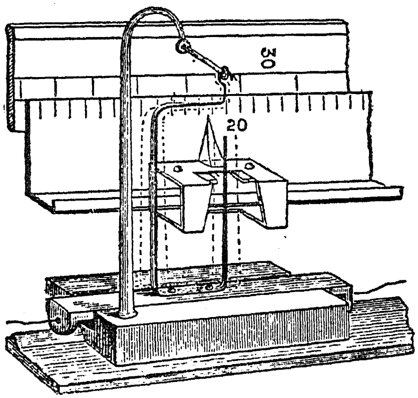


FIG. 9.—The above Diagram shows the Details of the Mechanism for drawing the Balancing Weight along the Tray of Lord Kelvin's Ampere Balance (see Plate 2) to establish equilibrium between the torque or turning force due to the weight and that due to the attractions of the fixed and movable coils.

Lord Kelvin contributed largely to the invention of currents and potential-measuring instruments of a standard type. He realised from the first start of electric lighting that accurate measuring instruments would be required with which to compare others.

He invented an ampere balance of the following kind. To the extremities of a scale beam he attached two circular coils which were placed between a pair of fixed coils at each side (see Plate 2, page 273). All six coils were joined in series so that when a current was sent through them the scale beam was tipped over to one side by the attractions and repulsions of the currents in the coils. The balance was then restored by sliding a weight along the beam (see Fig. 9). The position of this weight gave at once the value of the current on reference to a calibration table. To allow the current to pass in and out of the coils fixed to the swinging scale beam, Lord Kelvin suspended the beam by a number of fine wires attached to it and to fixed supports. The beam was thus free to oscillate, but the

current could pass through these flexible ligaments. These ampere balances were constructed by Lord Kelvin for various ranges of current measurement. He also invented a very useful form of electrostatic voltmeter (see Fig. 10). In this instrument a number of paddle-shaped sheets of thin metal are attached to an axis suspended by a wire. These plates are placed with planes parallel but with a certain interspace. These suspended plates are made to hang midway between a number of fixed plates in such fashion that if the fixed and movable plates are oppositely electrified they would attract each other, and so rotate the column of movable plates through an angle proportional to the difference of potential of the plates.

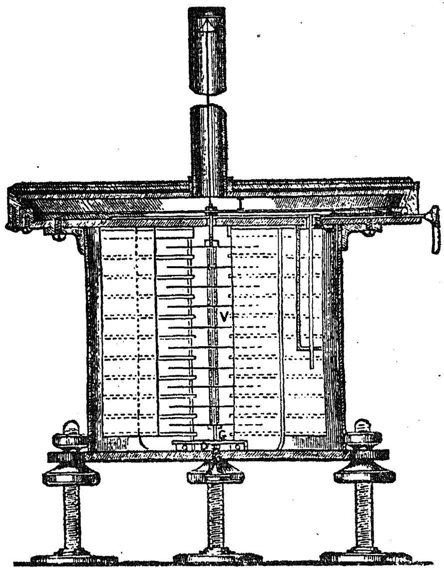


FIG. 10.—Lord Kelvin's Electrostatic Voltmeter. There are a set of plates or vanes V attached to an axis suspended by a torsion wire, and these vanes are more or less attracted in between certain fixed plates when the two are at different potentials.

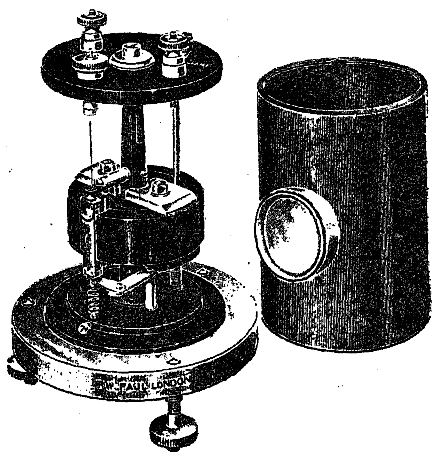
These electrostatic voltmeters can be made to measure very high voltages and have the property that they are equally useful for alternating as well as direct voltages (see Plate 3).

In course of time many useful types of ammeter and voltmeter were invented depending upon the heating and, therefore, the expansion of a wire through which a current flowed. The first of these was the hot wire voltmeter invented by Major Cardew, and other types were later brought into use based on the same principle.

An especially good form of laboratory ammeter and voltmeter are the so-called movable coil instruments, useful representatives of which are manufactured by Mr. Edward Weston in the United States.

In these a permanent steel magnet has a small coil of wire pivoted between its poles. The current is led into and out of this coil by flexible wires. The coil is placed with its magnetic axis perpendicular to the

lines of the interpolar field of the magnet and when a direct current is passed through the coil it turns so as to endeavour to place its magnetic axis parallel to the field. This effort is resisted by a spiral spring, similar to the hairspring of a watch, which is attached to the coil. The coil carries a long light pointer which moves over a scale of degrees, and the instruments can be calibrated to read in amperes or in milliamperes, that is thousandths of an ampere. Similar instruments are constructed as voltmeters (see Plate 4, middle diagram). Mr. Paul designed an especially sensitive form of direct reading movable coil microammeter for measuring very small currents. The majority of direct current ammeters and voltmeters are now moving coil instruments (see Fig. 11).



[*By permission of the Cambridge and Paul Scientific Instrument Co., Ltd.*

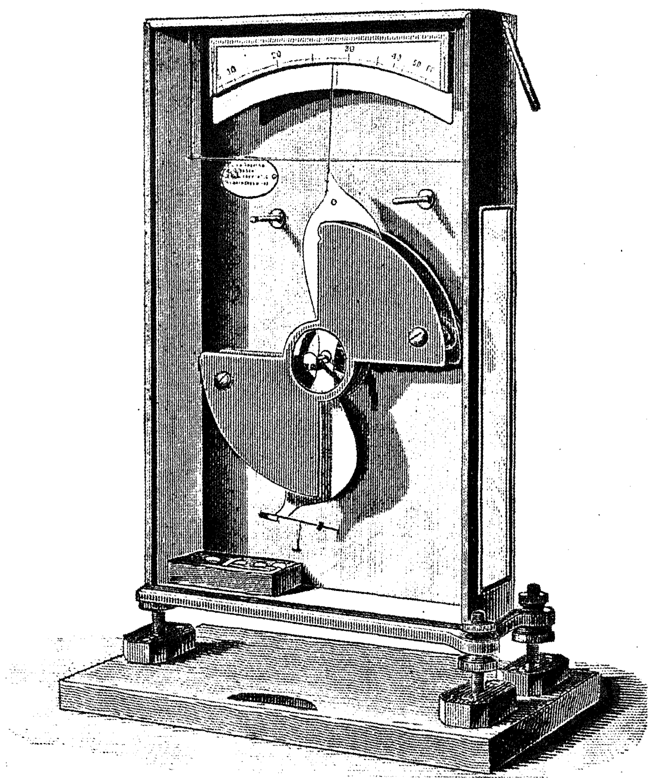
FIG. 11.—A Movable Coil Galvanometer (Paul). It comprises a fixed, nearly circular, magnet and a coil of wire suspended in its field. When a current flows through the coil it endeavours to turn so as to set its axis in the direction of the magnetic force. This movement is observed by a mirror fixed to the coil.

The establishment of electric generating stations called for the invention of special types of large scale instruments for measuring the large currents and high voltages employed, both direct current and alternating.

All electrical engineers and instrument makers owe a great debt of gratitude to the scientific investigators who undertook the researches necessary to establish our system of electrical units on an absolute basis and in close relation to the mechanical and thermal units, so as to reduce to a minimum the labour of technical calculations.

In Great Britain, Lord Kelvin, Professor James Clerk Maxwell and Lord Rayleigh (third baron) were the leaders and pioneers in this work in the latter half of the nineteenth century. They were aided and followed by a number of very able investigators, chiefly Cambridge men and workers in the Cavendish Laboratory, and eminent physicists in the United States, in France and Germany joined in the prosecution of it. The

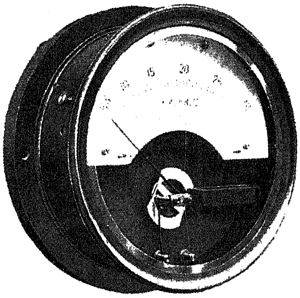
PLATE 3.



A Kelvin Electrostatic Voltmeter for measuring High Voltages, say, 2,000 to 20,000 volts. The paddle-shaped metal plate is suspended on knife edges and the electric attraction between it and the fixed quadrant plates, when they are at different potentials, draws in the movable plate to an extent determined by their potential difference.

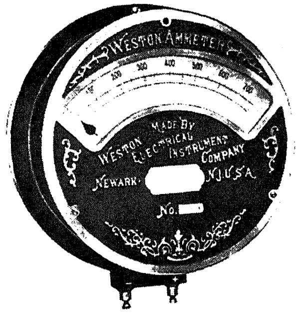
[*To face page* 280.

PLATE 4.

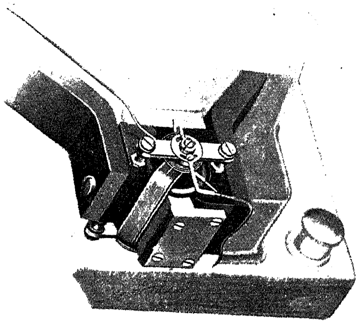
[*By permission of Messrs. Johnson and Phillips, Ltd.*

Johnson and Phillips Hot Wire Voltmeter and Ammeter.



[*By permission of Messrs. The Weston Electrical Instrument Co.*

Weston Ammeter.



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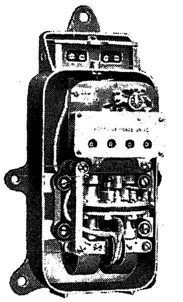
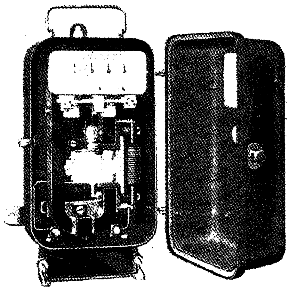
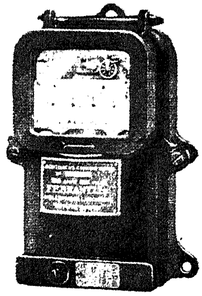
The Movable Coil of a Weston Ammeter.

Chamberlain and Hookham Electric Ampere-hour House Meter.



[*By permission of Messrs. Ferranti, Ltd.*

Ferranti Electric House Meter.

starting point for all this work was the determination of the ohm or unit of electrical resistance.

By Joule's law the rate at which heat is produced in a conductor by an electrical current is proportional to the product of the resistance and to the square of the current strength. But heat is a form of energy and, therefore, the rate of production of heat is measurable in the same units in which we measure mechanical power or rate of doing work.

We have seen that the square of the strength of a current is directly measurable in terms of a force, and a force multiplied by the velocity of its point of application is equivalent to a power or rate of doing work.

Hence, it follows that an electrical resistance must be measurable in terms of a velocity and the absolute unit of resistance must be 1 centimetre per second.

This, however, is too small for practical use and, hence, the ohm was defined to be 1,000 million centimetres per second. The British Association Committee already mentioned issued in 1865 certain wire standards of resistance called B.A. units, which were at that time supposed to represent the theoretical ohm in resistance, but as a matter of fact these units were too small, being in reality only 986·76 million centimetres per second instead of 1,000 million. The B.A. Committee in 1865 constructed a number of standard coils of different alloys which were intended to represent the ohm at certain temperatures marked on them. These coils (about half a dozen) were in 1874 deposited at the Cavendish Laboratory, Cambridge, soon after Professor Clerk Maxwell was appointed Professor of Experimental Physics and was organising the laboratory. In 1878 Professor Maxwell suggested to the author to undertake a careful re-comparison of these coils with the object of ascertaining if they had remained constant.

Previous comparisons had been made by Messrs. Matthiessen and Hockin in 1865, and others by Messrs. Chrystal and Saunder in 1876. The author designed a special form of resistance balance for comparing the coils by a method suggested by Professor G. Carey Foster, which enabled the difference in resistance between any two coils to be quickly ascertained (Fig. 12). The coils were tested at many different temperatures and a chart prepared, showing by lines on it the mode in which the

resistance of each coil changed with rising temperature. A dot was placed on each line corresponding to that temperature at which the B.A. Committee considered it represented an ohm. These dots ought to have been arranged in one horizontal line. As a matter of fact they were very irregularly arranged. It can easily be shown that the most probable value of the B.A. unit was obtained by taking the centre of gravity of these points. The author therefore was able to prove that the resistance

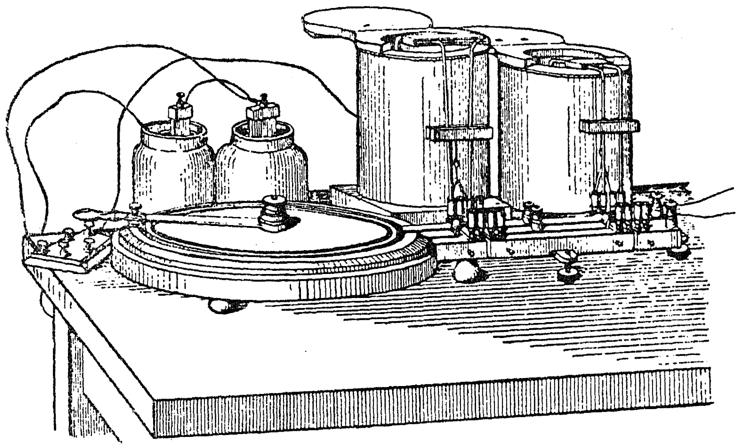
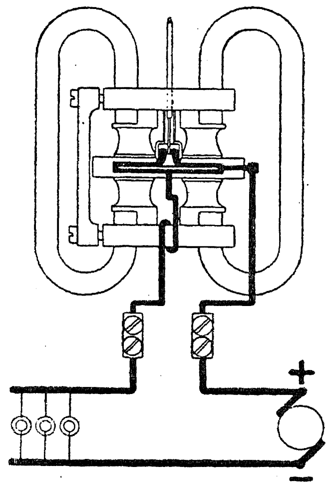


FIG. 12. — A Perspective View of the Fleming Resistance Balance for comparing Standard Resistance Coils. For many years it was in use at the Cavendish Laboratory, Cambridge, and is now at the National Physical Laboratory, Teddington, Middlesex. The principle of the instrument is that the difference in resistance between two coils of wire of nearly equal resistance can be measured in terms of the resistance of an observed length of a wire which is laid around a circular disk of ebonite. See also Plate 5, upper diagram.

of one particular coil taken at a certain temperature most probably represented the B.A. unit which the original Committee thought represented the theoretical ohm. Soon after the early and lamented death of Maxwell in November, 1879, the late Lord Rayleigh was invited to succeed him as Professor of Experimental Physics at Cambridge. Lord Rayleigh decided that a piece of work urgently necessary was a redetermination of the absolute value of this most probable B.A. unit of resistance, and with the assistance of Mrs. Sidgewick he set up the rotating coil apparatus for redetermining it by Lord Kelvin's method. Later

on Sir Richard Glazebrook and many others made redeterminations of the ohm by other methods. The result of this work was to prove that the B.A. unit was about 1·35 per cent. too small to represent the theoretical ohm. As a final upshot of much discussion at electrical congresses an International agreement was reached, that the theoretical ohm should be considered to be represented by the resistance of a column of pure mercury contained in a uniform glass tube 1 square millimetre in cross section and 106·3 centimetres long taken at 0° C., the mercury to have a mass of 14·4521 grammes. This unit is now called the *International ohm.* In this way standards were constructed for deposit at various places and copies made in wire comprised of manganin or other alloys for general use.

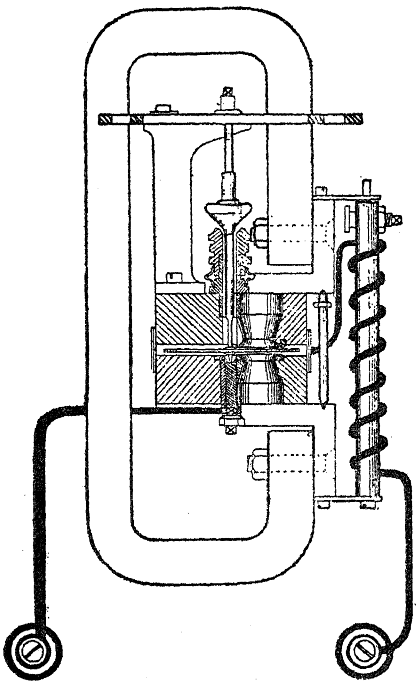


[*By permission of Messrs. Ferranti, Ltd.*

FIG. 13.—Section of a Ferranti Electric House Meter for measuring electric quantity supplied in the form of direct current. It comprises a metal disk varnished except at the edge and immersed in mercury in a narrow cavity between the poles of a pair of magnets. When an electric current passes in radial directions through the disk it acts like an electric motor and rotates in the transverse magnetic field. The number of rotations it makes in a given time is proportional to the quantity of electricity which has passed.

As a result of legislation electric supply companies and local authorities were authorised to sell electric energy by meter to consumers and a large amount of invention was expended in the twenty years between 1880 and 1890 in devising forms of electric quantity and energy meters for use in houses and buildings taking a public supply, called ampere-hour and watt-hour meters. The original Edison zinc sulphate meter is now defunct, and mechanical meters which record on dials like gas meters the units used are nearly always employed. These meters are in fact small electric motors, the speed of which is exactly proportional to the electric power which is being delivered to the circuit to which they are connected and, therefore, the number of their revolutions in a given time is proportional to the energy which has passed through them (see Figs. 13 and 14 and Plate 4). Electric house meters may be divided into two classes —(i.) those which measure quantity of electricity, called ampere-hour

meters, and (ii.) those which measure electric energy, called watt-hour meters. Since we are charged by unit for electric energy the first class of meter only measures electric energy on the assumption that the electric pressure or voltage is constant. Meters are also divided into direct current and alternating current meters. Good examples of direct current quantity or ampere-hour meters are the well-known meters of Ferranti (Fig. 13) and Chamberlain and Hookham (Fig. 14) in which a disk of copper is placed with its plane perpendicular to the field of a permanent magnet. The current to be metered is sent through the disk from centre to edge and the disk is therefore set in rotation in the field. The speed of revolution is proportional to the current strength and the number of revolutions in a given time to the quantity of electricity that has passed. A counter like that of a gas meter is attached to the disk and the dials can be set so as to measure in units.



[*By permission of Messrs. Chamberlain & Hookham, Ltd.*

FIG. 14.—Section of a Chamberlain and Hookham Ampere-hour House Meter for measuring the electric quantity of direct currents. It operates on the same general principles as the Ferranti meter (see Fig. 13) but with some differences in construction. The rod electromagnet at the side is to compensate for the slight fluid friction of the mercury.

By 1885 it had become clear that some means would have to be devised for checking these innumerable quantity and energy meters and also verifying commercial ammeters, voltmeters, resistance coils, etc., to maintain accuracy, just as the Board of Trade test and certify weights and measures. The author therefore read a paper to the Society of Telegraph Engineers in November, 1885, entitled, "On the necessity for a National Standardising Laboratory for Electrical Instruments." At that date there had been no proposals for establishing national electrical

or physical laboratories in any country. In this paper it was suggested that such an institution should be established, one of the duties of which should be to test and certify electrical instruments for accuracy, just as thermometers and watches were at that time tested at Kew Observatory. Another duty was suggested, viz., that of undertaking quantitative researches which were of too costly or too prolonged a character to invite readily private enterprise. The suggestions of the author created great interest, and all those who took part in the discussion approved of the project.

About two or three years later the suggestions bore fruit, when the Board of Trade established a small electrical laboratory in Whitehall and appointed an official electrical adviser, the first of whom was Major P. Cardew, R.E., who was succeeded by Mr. A. P. Trotter. This laboratory did very valuable work until a larger project was set on foot resulting in the establishment of a national physical laboratory. Prior to this date, however, an Imperial Institute, called shortly the Reichsanstalt, had been founded in Berlin, and similar institutions, called the Laboratoire Central d'Électricité, in Paris, and the Bureau of Standards, Washington, U.S.A., came into existence later on.

The establishment of a National Physical Laboratory in Great Britain had been an object of desire to many who realised the great importance of scientific research in connection with industrial progress. Attention was drawn strongly to the subject by Sir Oliver Lodge and by Sir Douglas Galton in a presidential address to the British Association in 1896.

A year or so later the Chancellor of the Exchequer appointed a Treasury Committee, of which Lord Rayleigh was chairman, to advise on the matter. This committee visited the Reichsanstalt at Berlin, and as a final result, by Government grants and private donations, a laboratory was established and equipment provided in Bushy House, Bushy Park, Teddington. This laboratory was opened by the then Prince of Wales, now His Majesty King George V., in March, 1902. The laboratory has in the last eighteen years immensely extended its operations, and has rendered most important services to science and to the nation by its researches.

We must next turn to consider the progress which electrical theory has made in the last half century.

Prior to 1870 a great revolution had been effected in our mode of regarding electrical phenomena, due to the work of Faraday and Maxwell (Plates 6 and 7). The philosophers in the early part of the nineteenth century were wont to regard the attractions or repulsions of electrified bodies, magnets, or electric currents as actions exerted across empty space, without concerning themselves about any possible mechanism by which they are produced. Nevertheless, even Newton himself had raised objections to the acceptance of action-at-a-distance, as it was called, and Ampère, Henry, and Faraday had all inclined to the opinion that electrical phenomena must in some way be dependent upon the existence of a universally diffused medium, most probably the same as that called the *æther*, which had been hypothecated by Thomas Young and Fresnel to explain the phenomena of light. Faraday had gone much farther, for he had shown that electrical attractions depended upon the nature of the material, insulator or dielectric, as he called it, in which the attracting bodies are immersed.

Thus, if we electrify two pith balls with similar electricity, they repel each other with a certain force *in vacuo*. If, however, they are plunged into turpentine or paraffin oil, they will repel each other with less force, showing that the medium between them is concerned in the force production. Faraday viewed all these actions as the result of "lines of force" existing in the medium.

If we place a sheet of card over a bar magnet and sprinkle iron filings on the card, these arrange themselves in beautiful curved lines proceeding from the poles of the magnet (see Plate 5, page 281, lower diagram). Faraday thought that these lines are evidence of some state existing in the space which the filings render visible, just as dust in the air renders evident the path of rays of light, though in perfectly dustless air those rays would not be visible, unless they fall on some reflecting object. Magnetic force, however, does not proceed in straight lines like light, but in curved lines, which spring from North Pole to South Pole through the surrounding space.

Faraday considered that electric and magnetic attractions were due to the tendency of invisible lines of electric or magnetic force to shorten themselves, the ends of these lines terminating either on oppositely charged

(+ and −) electric substances or on dissimilar (N and S) magnetic poles.

Faraday, however, was not a mathematician, and he had not been able to present his ideas in such form as to command the assent of mathematical physicists generally.

James Clerk Maxwell (1831–1879) was one of that small but brilliant group of Cambridge men, including Lord Kelvin (William Thomson), Lord Rayleigh (John William Strutt), Sir George Gabriel Stokes, John Couch Adams, and a few others, who in the latter half of the nineteenth century made contributions of untold value to human knowledge. Even as a boy Maxwell exhibited remarkable powers of origination and discovery.

After taking his degree as Second Wrangler, Maxwell obtained a Trinity Fellowship, and in 1856 was appointed Professor of Natural Philosophy in Marischel College, Aberdeen, and subsequently, in 1860, to a similar chair in King's College, London.

In 1865 he retired to his estate in Scotland, where he had leisure to work out his great electromagnetic theory and write *A Treatise on Electricity and Magnetism*, which has left an imperishable mark on the history of the science.

In 1870 the seventh Duke of Devonshire built and equipped the Cavendish Laboratory at Cambridge for physical research, and in 1871 Maxwell, then at the plenitude of his powers, was invited to be the first Professor of Experimental Physics, and commenced his teaching work.

He gathered round him a small but devoted group of advanced students.

The author went up to Cambridge in October, 1877, with the chief object of working under Maxwell in the Cavendish Laboratory.

At that date the bulk of Cambridge undergraduates working for degrees attended college lectures and "coached" with private tutors, but the University Professors, even those of world-wide fame, such as Stokes, Adams, Maxwell or Cayley, had very small lecture classes. Maxwell's lectures were rarely attended by more than half-a-dozen students, but for those who could follow his original and often paradoxical mode of presenting truths his teaching was a rare intellectual treat, a lifelong inspiration, and a treasured memory.

The publication in 1873 of Maxwell's *Treatise on Electricity and Magnetism* marks a great epoch in the history of the subject. Before that time, however, he had introduced important new conceptions into electrical theory.

He had his attention turned to Faraday's mode of regarding electrical effects by Lord Kelvin, and he set himself to translate these ideas into mathematical language.

Faraday showed that, if a metal sphere charged with electricity, say,

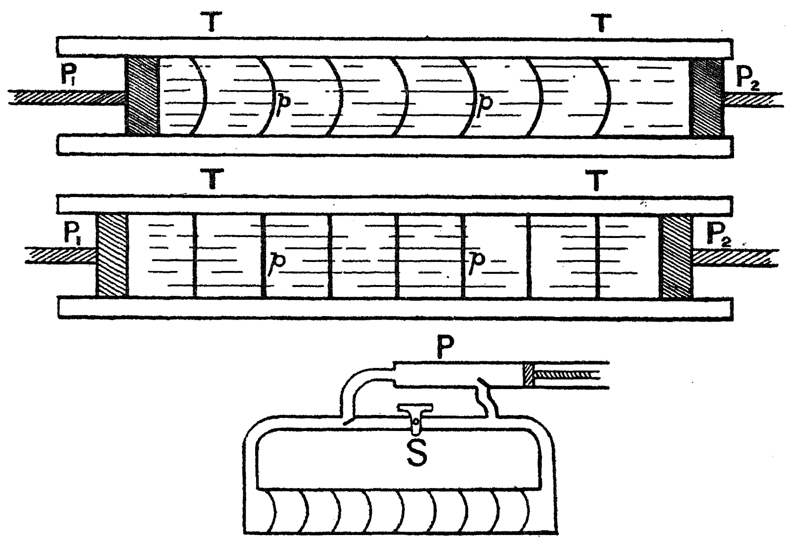


FIG. 15.—A Model to illustrate Maxwell's conception of Electric Displacement in Dielectrics or Insulators. TT is a tube filled with water with elastic partitions p across it. P_1P_2 are pistons. When P_1 is pushed in it makes a displacement of the elastic partitions.

positively, was introduced into a closed metal vessel, it created by induction an equal charge of negative on the interior of the vessel, and an equal charge of positive appeared on the outside. Maxwell regarded this effect as due to a *displacement* of electricity through the dielectric. As an illustration of his use of this term take the following example :— Suppose a pipe to have a large number of elastic partitions across it, made, say, of thin indiarubber sheet. Let all the cavities between the partitions be filled with water (see Fig. 15). Let there be a tightly-fitting piston

at each end of the pipe. If, then, we force in the piston at one end it will displace or move the water all along the pipe. Each elastic partition will be bulged in one direction, and the piston at the other end of the pipe will be moved outwards. The partitions prevent the water from flowing along the pipe continuously, but, owing to their elasticity, they do not prevent a limited displacement of the water.

Electricity behaves in many respects like an incompressible fluid. We can cause it to flow continuously through a conductor, which answers to an unobstructed pipe, but we cannot create an electric current through an insulator ; we can only make a limited displacement, which corresponds to the water movement in a pipe with elastic partitions across it.

Maxwell saw that such elastic displacement of electricity through insulators was, in effect, an electric current *whilst it is changing*, and must, therefore, produce a magnetic force (just as does a current of conduction) during its increase or decrease.

Again, we know that, when a magnetic pole is brought up to a closed conducting circuit, the insertion of lines of force into the circuit produces, as Faraday showed, an electromotive force in the circuit ; in other words, it generates an induced conduction current. Maxwell extended this principle to insulators, and said that the effect of varying the number of lines of force passing through a dielectric is to create an induced displacement current.

Maxwell then expressed these facts in mathematical language and gave what are now called the Maxwellian equations of electromagnetism. These equations showed at once that the quantities or effects we call magnetic flux and electric displacement are propagated through dielectrics in waves with a finite velocity and not instantaneously.

The reasoning by which Maxwell arrived at this conclusion was contained in a paper sent by him to the Royal Society of London in October, 1864, and published in the *Transactions* in 1865, entitled "A Dynamical Theory of the Electromagnetic Field."

An eminent mathematician once said to the writer, soon after Maxwell's death, that he considered this paper, by its marvellous originality and insight into nature, to be one of the very greatest productions of the human mind.

Maxwell showed that the velocity with which these electric or magnetic forces are propagated through a dielectric are inversely proportional to the square root of the product of the dielectric constant, or, as Faraday called it, specific inductive capacity and its magnetic permeability. Since no dielectric or insulator except liquid oxygen has a magnetic permeability differing sensibly from unity we can simplify the above statement by saying that Maxwell proved that the velocity of propagation of electromagnetic effects is inversely as the square root of the dielectric constant.

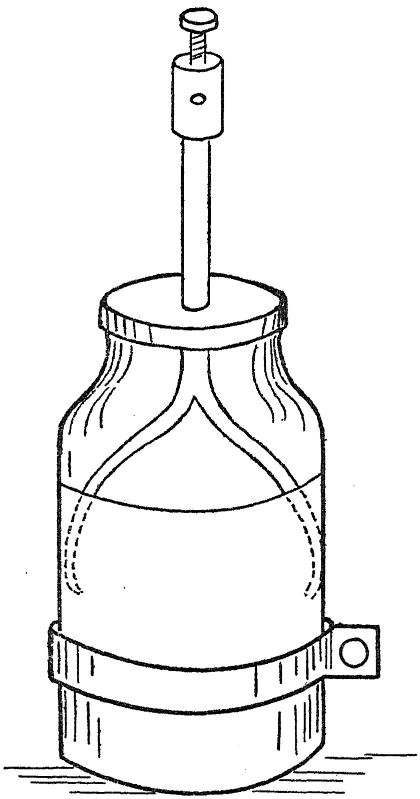


Fig. 16.—A Leyden Jar. It consists of a bottle coated within and without halfway up with tinfoil. It is, in fact, an electrical condenser.

It is necessary to explain the meaning of this statement.

Faraday constructed, in 1837, a sort of Leyden jar or condenser consisting of a metal sphere supported concentrically in the interior of a spherical metal shell (see Figs. 16 and 17). He found that if the interspace was filled with air or was vacuous that this Leyden jar had a certain capacity for electricity which may be arbitrarily called unity.

If, however, the interspace is filled with any other liquid or solid insulator, say paraffin wax or sulphur, then the capacity is represented by a larger number, say two or four or more. This number, which represents the increase in capacity compared with an air condenser, is called the *dielectric constant* of the insulator. The term is not very apt because the numerical value is not constant, but depends on temperature, time of charging and other conditions of the dielectric. These numbers, which Faraday called the *specific inductive capacities*, are relative numbers, but the question

arises as to the absolute values. This absolute value can be arrived at as follows: An electric current may be measured in two ways: First, we may regard it as a movement of electricity in a conductor, and then the unit current is that in which unit quantity flows past any section of the conductor per second. The unit quantity of electricity may be defined as that which when given to a small sphere repels another like charge at a unit of distance with a unit of force. But this, as we have seen, depends on the dielectric constant of the insulator, viz., the air or liquid in which the spheres are placed, and the force for a given charge is inversely as the dielectric constant of the medium.

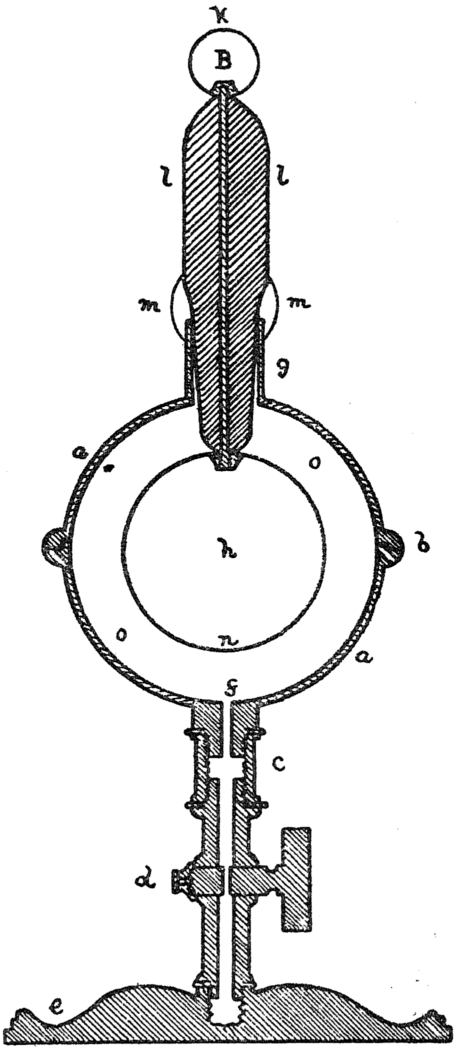


FIG. 17.—Faraday's Leyden Jar, consisting of two metal balls one enclosing the other. The space between could be filled with any solid or liquid insulator and its dielectric constant or specific inductive capacity thus found.

Again we can measure a current by the magnetic force it produces around it, and this depends upon the magnetic permeability of the medium in which the conductor is immersed.

By appropriate means we can measure a given current in the first way, viz., in electrostatic units, or in the second way in electromagnetic units, and the ratio of the first to the second gives us the value of the ratio of unity to the square root of the product of the dielectric constant and the magnetic permeability of the medium in which the experiment takes place.

An experiment of this kind was suggested by Maxwell, and made by

him in 1868. A year before that, Lord Kelvin and Mr. W. F. King had made a similar measurement of the ratio of the units, as it is called, and even as far back as 1856 Weber and Kohlrausch had made an approximate determination. The remarkable fact which emerged from these measurements was that the ratio of the electrical units and, therefore, the velocity of propagation of an electromagnetic impulse, or wave through a dielectric, was expressed by the same number as the velocity of light through it, which is 300,000 kilometres per second nearly in empty space. Maxwell therefore made the brilliant suggestion that light must be an electromagnetic phenomenon and that waves of light were electromagnetic waves. This idea, as we shall see, laid the foundation for wireless telegraphy.

A consequence of Maxwell's theory was that the optical refractive index of a transparent dielectric should be proportional to the square root of the dielectric constant at least in those cases in which the latter does not change much with frequency. A ray of light travels more slowly in a transparent body than *in vacuo*. The index of refraction is a measure of the slowness or reciprocal of the velocity of the ray, taking that *in vacuo* to be unity. At the date when Maxwell proposed his theory there were comparatively few dielectrics for which the dielectric constant had been measured.

When, however, a large number of observations had been made it was found that all transparent bodies might be divided into two broad classes, first, a class including the gases, paraffin oils, and certain other hydrocarbons, for which the law was pretty accurately obeyed, and secondly, a class of substances such as water, alcohol, ether, glass, mica, and many other substances for which it was not nearly obeyed. Thus, for instance, the dielectric constant of water when measured with steady or low frequency alternating currents is a number near 80 or 81, and the square root of this is 9. But the optical refractive index of water is about 1·33. Hence, there is a great discrepancy.

Sir James Dewar and the author, working together about 1896 and 1897, made a very large number of determinations of dielectric constants of various substances at very low temperatures (about −200° C.) by means of liquid air, and found that in all cases these abnormally high dielectric constants like those of water (= 80) and ethylic alcohol (= 25) came

down to much smaller values comparable with those required by Maxwell's theory, when the substance is cooled to near —200° C.

Long before that time epoch-making researches had been made in the practical production of Maxwell's electromagnetic waves. Maxwell himself had had his attention so much taken up with other work during the last ten years of his life that he never attempted to find a method of producing electromagnetic waves differing in wavelength from those of light, which are, on an average, about 1-50,000th part of an inch in wavelength, that is to say, from crest to crest. A brilliant physicist, G. F. Fitzgerald, had, however, suggested that the discharge of a Leyden jar might be made to produce Maxwell's waves.

Even as far back as 1842, Joseph Henry, in the United States, had opined that the discharge of a Leyden jar was not always a movement of electricity in one direction but might be an oscillatory movement. Helmholtz, in 1847, had re-affirmed this belief, but it was to Lord Kelvin, in 1853, that we owed the complete mathematical discussion of the problem, and the proof that when a Leyden jar is discharged through a circuit of low resistance the electricity rushes backwards and forwards in gradually decreasing currents, thus giving the so-called oscillatory discharge (see Plate 8, page 289, upper diagram).

Soon afterwards Feddersen, and later on Vernon Boys, Trowbridge, and many others, photographed the oscillatory discharge of a Leyden jar, gave experimental proof of the existence of these oscillations and confirmed Kelvin's law that the frequency is proportional to the square root of the product of the capacity of the jar and the inductance of the discharging circuit.

Sir Oliver Lodge, about 1887 and 1888, made a very particular study of this oscillatory discharge of the Leyden jar and had been able to produce stationary electric waves on long wires.

About the same time H. R. Hertz, in Germany, succeeded in finding a method for generating Maxwell's electromagnetic waves of any required wavelength and also invented a method of detecting them, which was equally necessary. Hertz's discovery really consisted in the invention of a kind of Leyden jar, which when discharged gets rid of its energy, not only as heat in the spark and circuits, but throws off or radiates a

large proportion of it in the form of electric waves. Hertz's oscillator or radiator consisted of a pair of rods placed in line with each other. Each rod had a spark ball at the contiguous ends and a plate of metal at the other extremity (see Fig. 18). These plates had capacity with respect to each other. This condenser is charged by connecting the balls to the secondary circuit of an induction coil and adjusting the distance of the balls, which must be highly polished, until a bright, short crackling spark passes between them. This indicates that an oscillatory discharge is taking place. Hertz's receiver or resonator consisted of a ring-shaped wire with a little air gap in it, the ends of the wire being brought very near together. When this ring resonator was held at a distance from the

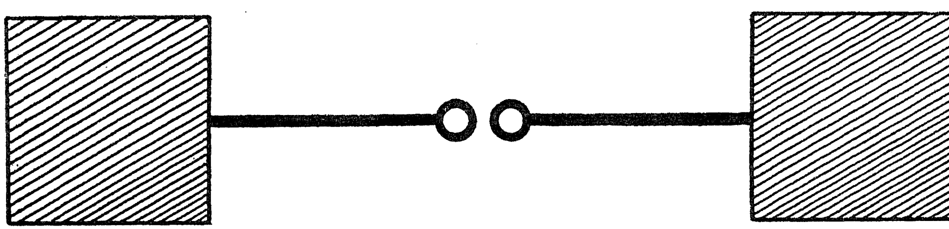


FIG. 18.—Hertz's Oscillator or Radiator, comprising two metal rods terminated at one end by spark balls and at the other by capacity plates. It forms a kind of Leyden jar.

oscillator with its plane parallel to the axis of the latter small sparks were seen in the air gap of the resonator (see Fig. 19).

Hertz placed his oscillator at one end of a long room, the opposite wall of which was covered with zinc. He then placed the ring receiver at various distances from the end wall and found that the sparking occurred at certain regular intervals with places of non-sparking in between. This showed that stationary electric waves in space were being produced. He found that the electric radiation proceeding from his oscillator could be reflected from metallic surfaces like light, and refracted by large prisms made of pitch.

In a word, he had succeeded in producing Maxwellian electromagnetic waves of wavelength much greater than those of light, but resembling them in other properties.

Hertz's discoveries and researches produced a great sensation in

scientific circles in 1888, and all the world over physicists began to repeat and extend them. Sarasin and de la Rive, A. Righi, Lodge, Fitzgerald and Trouton, Trowbridge and many others made contributions of great importance.

The great interest consisted in being able to produce a kind of invisible light or non-eye-affecting radiation which had all the characteristics of visible light and radiant heat and could be reflected, refracted, converged by lenses, polarised by gratings, and to which some bodies were opaque and others transparent.

Some investigators, such as Lebedew, Righi, Bose, and the author, devised apparatus for the production of electric waves only a few inches in wavelength, with which striking experiments can be shown.

For this purpose we require a more sensitive detector of the waves than Hertz's ring resonator.

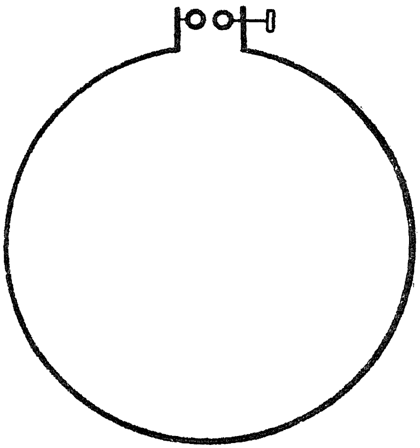


Fig. 19.—Hertz's Resonator consisting of a Wire Ring provided with a small Spark Gap.

In 1890, Professor E. Branly, in Paris, noticed that a tube loosely full of metallic filings would not conduct much electric current if placed in series with a voltaic cell and a galvanometer, but if an electric spark was made near it the conductivity suddenly increased. It was soon recognised that this effect was due to rapid electric oscillations taking place through the tube. Sir Oliver Lodge found that two loose or imperfect metallic contacts improved in conductivity when oscillations were passed across the junction, and named the device a coherer. In 1894, at the Royal Institution, London, Lodge gave a lecture on the work of Hertz, who died early in 1894, and exhibited numerous quasi-optical experiments with Hertz's oscillator and a detector consisting of a Branly tube loosely packed with iron filings and with his own loose metallic contact or coherer (see Fig. 20). Lodge, and Popoff, of St. Petersburg (or Petrograd), invented methods, by clockwork or by a self-acting electromagnet vibrator like an electric bell, for administer-

ing a tap or series of taps to the Branly tube, then commonly called a coherer, so as to keep the filings in a loose, high resistance condition.

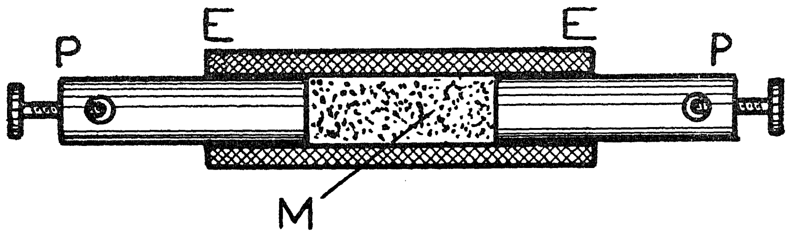


FIG. 20.—A Coherer of Branly or Lodge consisting of a tube E filled loosely with metal filings M and closed by two metal plugs P. In their loose condition the filings are non-conductive for electricity but cohere and conduct when an electric spark is made near them.

Popoff inserted a relay and voltaic cell in series with the coherer tube, so that when oscillations passed through the tube and made the filings conductive the cell sent a current through it and through the relay which then started in action an electric bell, the hammer of which was made to strike the coherer tube and bring the filings back to a non-conductive condition. Popoff attached the coherer by a wire to a lightning conductor, by which it was set in action by distant atmospheric discharges creating the natural electric waves in the atmosphere (see Fig. 21). By the close of the nineteenth century Maxwell's theory of electromagnetic phenomena had been generally accepted. It was considered as experimentally proved that electromagnetic effects were propagated through space as waves produced in the immaterial medium called the æther, which it had been necessary to postulate to account for optical phenomena.

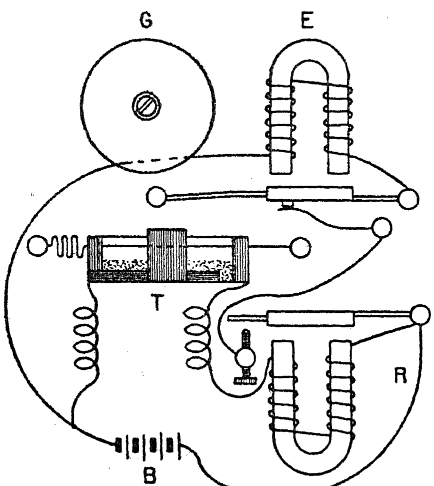


FIG. 21.—Popoff's arrangements for tapping back a Coherer T to a state of sensibility by means of an Automatic Tapper worked by an Electromagnet E.

Maxwell's theory, however, gave no clue to the nature of electricity

itself. According to Maxwell the magnetic effects due to an electric current were propagated through the surrounding dielectric, and the wire or conductor acted merely as a guide. The next important advance in our knowledge came from the remarkable researches of Sir J. J. Thomson, who succeeded Lord Rayleigh in 1884 as Cavendish Professor of Physics in the University of Cambridge. The brilliant phenomena connected with the discharge of electricity through gases in so-called vacuum tubes had long attracted great attention. Faraday, Plücker, Hittorf, Goldstein, Spottiswoode and Moulton and Crookes had devoted great attention to it.

Sir William Crookes, in particular, had made notable discoveries connected with electric discharge in very high vacua between 1875 and 1890. If a glass tube has platinum wires, called electrodes, sealed into the ends and if these are connected to the secondary terminals of an

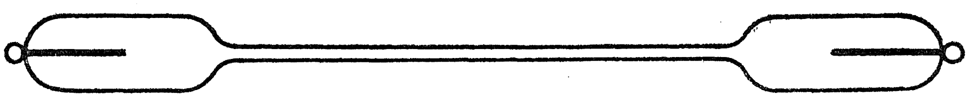


FIG. 22.—A Vacuum Tube or Tube filled with Rarefied Gas.

induction coil, so as to make a discharge through the tube, very different phenomena are observed as the tube is gradually exhausted of its air (see Fig. 22).

Starting from the negative terminal, called the cathode, and assuming that the exhaustion of the tube is fairly high, we find the cathode covered with a thin layer of luminosity and beyond that a dark space called the Crookes' dark space, named after the discoverer. The length of this space depends on the vacuum and increases with it.

Beyond that is another region of luminous glow in the gas and then a second dark space called the Faraday dark space. After that the tube is filled with glow right up to the positive terminal and under certain conditions of pressure and current this glow is cut up into bright and dark spaces called the stratification.

When the pressure of the gas in the tube is not very low the dark spaces near the cathode are so thin that they are hardly visible, and the tube seems to be full of the stratified glow light.

When the tube is very highly exhausted and is of bulbous shape the Crookes' dark space may fill the whole tube, and under these conditions the walls of the tube may become phosphorescent. Plücker discovered in 1859 that under these conditions something is projected or radiated from the cathode which is called cathode rays, and Hittorf found that these rays cast shadows of solid objects in the tube on the wall of the vessel (see Fig. 23). This experiment was very prettily illustrated by an apparatus of Crookes', called the shadow tube. In this a pear-shaped glass bulb of soda glass had a cathode sealed in at the narrow end and an anode near the wide end. Also it had a metal cross fixed to a hinge about three-quarters of the way along the tube. When the electrodes were connected to an induction coil, the tube being very highly exhausted, the glass became phosphorescent with a greenish yellow glow all over the region near the large end of the bulb; but the cross cast a well-defined black shadow or place of no phosphorescence on the glass, proving that the cathode rays are projected from the cathode in straight lines. The author found that if the bulb is surrounded by a circular coil, through which a strong electric current is sent, the shadow of the cross becomes smaller and is curiously rotated relatively to the actual cross, thus showing that the cathode rays are twisted into a spiral when they move along lines of magnetic force.

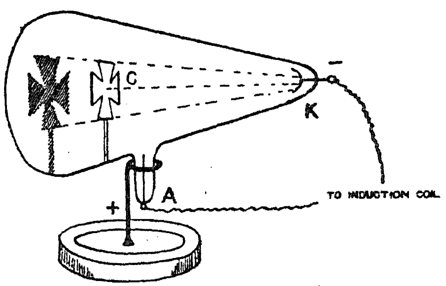


FIG. 23.—Crookes' Shadow Cross High Vacuum Tube.

Crookes also found that many substances, such as diamond, calcium sulphide, etc., became brilliantly phosphorescent when placed in highly exhausted tubes and exposed to the cathode rays. Crookes also proved that the cathode rays possessed momentum and could set in revolution little vanes or windmills placed inside the tube when they impinged on one side. He showed, as Plücker had done, that the cathode rays were deflected by a magnet and behaved as if they carried a charge of negative electricity. Crookes always upheld the view that the cathode rays were a material radiation, and he spoke of them as composed of matter

in a fourth state, or radiant matter more attenuated even than gases, in opposition to the view that the cathode rays were merely æther waves of some kind.

In 1895, W. Röntgen, in Germany, found that not only did the cathode rays make the glass of a Crookes' tube phosphorescent, but created also phosphorescence in paper covered with platino-cyanide of potassium or barium placed outside the bulb. Also he found that various substances differed in opacity to the external radiation, which he called X-rays. He created an immense public interest by showing that the bones and muscular tissues of the living body were differently transparent to these X-rays, so that it was possible to see the bones inside the living hand by placing the hand between a Crookes' tube and a phosphorescent screen. It was soon found that a better result was obtained by allowing the cathode rays from a concave cathode to impinge on a small plate of refractory metal placed inside the bulb at an angle of 45°, and that then the peculiar radiation, called the X-rays, was copiously sent forth from this metal surface or anticathode in the bulb (see Plate 8, p. 289, and Fig. 24). Dr. Coolidge invented a still more improved form of X-ray tube in which the cathode is a strip of tungsten which is rendered incandescent by an electric current.

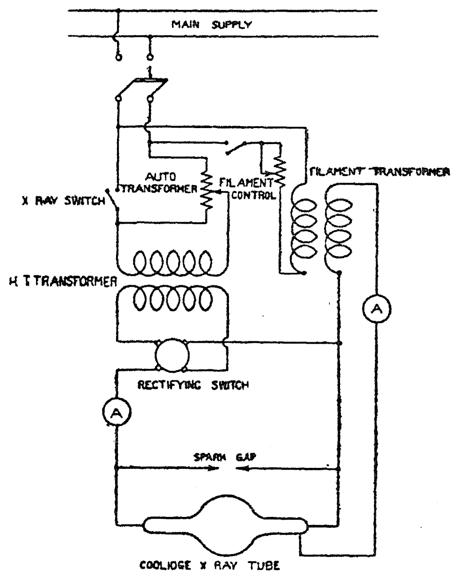


FIG. 24.—Arrangements for operating an X-ray Tube by rectified Alternating Currents of Electricity.

Sir J. J. Thomson announced in 1896 that these X-rays make a gas through which they pass a conductor of electricity.

About this date Thomson took up systematically the investigation of the nature of the cathode rays in a Crookes' tube, and by experiments of surpassing ingenuity and skill he was able to demonstrate that they are

composed of masses smaller than the smallest chemical atom, having only about an 1,800th the mass of an atom of hydrogen and probably a diameter only one hundred thousandth as great, and that they carry a negative electric charge which has a value of 477·4 billionths of an electrostatic unit ($= 4{\cdot}774 \times 10^{-10}$). In other words $\frac{1}{6}$th of a billionth of the quantity conveyed by 1 ampere in one second.

This small quantity of negative electricity is nature's unit, and is indivisible, that is, we can have no smaller quantity.

Thomson called these cathode ray particles *corpuscles*, but they are now generally spoken of as *electrons*. The negative charge carried by them is also called an electron.

Thomson found that the electrons have the same properties no matter what the nature of the residual gas or that of the cathode terminal might be.

The upshot of all the unspeakably important researches made on this subject during the last twenty years has been to show that these electrons are constituents of all chemical atoms and that collectively they form what we call negative electricity, the electron being, so to say, an atom of negative electricity.

Progress in penetrating the secrets of atomic structure and the nature of electricity became very rapid after 1896. In that year the eminent French chemist Becquerel found that salts of uranium possessed the power like X-rays of blackening a photographic plate and rendering the air conductive of electricity. A careful examination of this effect showed that some natural compounds such as pitch blende containing uranium were more powerful than pure uranium metal. This led to an exhaustive chemical investigation by M. and Mde. Curie, M. Belmont and M. Debierne, which was rewarded by the supremely valuable discovery of the unique element radium, and a whole series of other hitherto unknown elements, the study of which opened up an entirely new field of research in a new science of *radio activity* and atomic structure. In this department of research Sir Ernest Rutherford, who has succeeded Sir J. J. Thomson as Cavendish Professor at Cambridge, has taken an important part.

Very briefly it may be stated that recent research seems to support the view that the atoms of our chemical elements are structures which

contain according to the views of Rutherford a nucleus composed of a positive electric charge in which the gravitative mass of the atom chiefly resides, and that round this are placed in various rings or orbits a group of negative electrons in number about equal to half the atomic weight for all elements except hydrogen, in which there is one electron. We can separate certain of these negative electrons from atoms and the remainder is called a positive ion, but the complete isolation of positive electrons has not yet been accomplished. In other words, we only know positive electricity in association with atomic residues. No explanation has yet been reached of the close connection of the mass of the atom with the nucleus rather than the negative electrons. In a neutral atom the total negative and positive charges are equal.

A conductor is negatively electrified when there is an excess of electrons on it. This charge resides on the surface because the electrons mutually repel each other and so try to keep as far apart as possible. When neutral atoms have lost or gained electrons they are said to be ionised.

There is evidence that in a material which is a good conductor the majority of the atoms are in a state of incessant ionisation. Electrons are jumping from atom to atom in an irregular manner. If we apply an electromotive force, these free electrons are made to drift in one direction just as a swarm of bees in which each insect is flying hither and thither in an irregular manner can be moved by a breeze as a whole along a road. This drift of electrons in a conductor constitutes an electric current. A current produces heat in a conductor because this drift of the electrons causes them to collide with atoms and so increases the irregular motion, the energy of which is heat energy. The electron theory of electricity as now developed has given us a certain limited answer to the question, What is electricity? It has, however, raised as many difficulties as it has resolved. The exact relation of the electron to the æther has not yet been determined, if, indeed, there be an æther.

The true nature of electromagnetic radiation has yet to be made clear.

It is impossible within the brief limits of this chapter to mention even a fraction of the various theories of æther structure which have been proposed to account for optical phenomena.

Of recent years the discussion of certain observed effects has suggested fundamental changes in our ideas regarding space and time.

In the early part of last century Thomas Young and Augustin Fresnel found that two rays of light could under some conditions annihilate each other. This gave strong support to the view that light must consist in a motion of some kind in a medium because oppositely directed motions can neutralise each other; whereas if light consisted of a substance bodily transferred through space it is impossible to conceive how this mutual destruction of two rays of light could take place. At a little later date the discovery of the facts of the polarisation of light or that a ray of light may have different properties according to the side of the ray we are considering, showed Young and Fresnel that if light consists in vibrations of a medium these vibrations cannot be along the direction of the ray as in the case of sound waves, but must be transverse or across the direction of the ray.

It is well known that in the case of an elastic solid two kinds of waves can be set up in it, one in which the vibrations are along the direction of propagation of the waves, called longitudinal or compressional waves, and the other in which the vibrations are across that direction, and these latter are called transverse or distortional waves. In the case of an earthquake, waves of both kinds are created in the earth's crust and travel with different velocities. It is in general impossible in an elastic solid to establish transverse waves without also creating longitudinal waves.

If therefore the waves which constitute light are transverse waves, the medium in which they are created, viz., the so-called æther, must have qualities similar to those of an elastic solid. But no one has yet found any optical phenomena which suggest the existence of a longitudinal wave in the æther. Accordingly the philosophers who supported the hypothesis that light consists in vibrations in an æther were compelled to try to invent a structure for it which would enable it to propagate transverse but not longitudinal waves. An Irish mathematician, MacCullagh, was the first to propound such a theory, and Lord Kelvin also suggested a type of æther he called a labile or foam æther which had the above-mentioned quality.

Nevertheless, none of the elastic-solid theories of æther structure

complied with all the optical requirements. In 1864 Clerk Maxwell proposed his novel electromagnetic theory of light in which the waves consisted of rapid electric displacements or vibrations of electric force taking place at right angles to the direction of the ray. This theory abolished at once any difficulties connected with the propagation of a longitudinal wave and substituted an electromagnetic æther or medium for the assumed elastic-solid æther of Fresnel and Young, but it raised other difficulties. The question presented itself, Is the æther at rest in space and does the earth move freely through it like an aeroplane flying through the air ?

Certain astronomical phenomena, notably that of aberration, seemed to require a stationary æther through which the earth moves without disturbing it. On the other hand, an observation by Arago appeared to demand for its explanation the assumption that the æther round the earth at any rate moves with it. Experiments by Sir Oliver Lodge also indicated that material substances in rapid motion do not drag the æther along with them.

A critical test experiment was made in 1881 by an American physicist, A. A. Michelson, which was repeated in 1887 with great precautions by Michelson and Morley and designed to settle this question. It virtually consisted in measuring the time taken for a ray of light from a lamp to travel a certain distance and back in the direction of the earth's orbital motion in space, which is at the rate of about twenty miles per second, and comparing it with the time taken by the ray to travel an equal distance across the line of the earth's motion.

It admits of an easy proof that the time taken by a swimmer to swim 100 yards up stream and back again in a flowing river would be greater than the time the same man would take to swim 100 yards across stream and back again.

If we assume that the æther is at rest and the earth moves through it, then, since all motion is relative, we may consider that everything proceeds as if the earth were at rest and that a stream of æther is rushing through our laboratories at a speed of twenty miles a second. A ray of light sent out in any direction may then be regarded as a swimmer making his way through moving water. If the ray is sent a certain distance up the æther

stream and then reflected back again it ought to take a longer time to travel than if it proceeds an equal distance and back across the æther stream.

This was in fact the nature of the experiment of Michelson and Morley. When, however, the experiment was tried with rays of light it was found that, to the great surprise of the scientific world, light travelled at the same speed whether going with or against or across the direction of the earth's motion through space. In short, the result of the experiment was to show that we cannot detect by any optical or electromagnetic experiments whether the earth is moving or not relatively to the æther. In this matter it is just as it is with mechanical motions. If observers were enclosed in a room or box moving at uniform speed in a straight line through space no dynamical experiments they could make inside the room would enable them to tell whether they were moving or not relatively to other objects outside the room. The result of the Michelson and Morley experiment called forth two proposed explanations.

One propounded by Fitzgerald and by Lorentz is based on the hypothesis that material substances when moving through space, a wooden rod for instance, are slightly shortened in length in the direction of their motion.

Hence, in the Michelson and Morley experiment the longer time required for the ray to travel out and back in the direction of the motion of the apparatus through the æther as compared with that in the transverse direction is compensated by a supposed contraction of the structure in that direction which cancels the time difference. A German physicist, Einstein, has, however, proposed of late years an explanation which evades the necessity for any such hypothesis as that of Fitzgerald and Lorentz.

Einstein accepts in the first place as an experimental fact that the velocity of light is the same in all directions with respect to the earth's motion through space, and he proves that as a consequence of this we can no longer consider that stated spaces and times have absolute magnitudes independent of the motion of the observer or of the thing or event observed. In other words, there is no meaning in the statement that a certain thing has a length of one yard or a certain event has a duration of one hour unless we also state the relative motion of the observer and of the system

or locality in which the measurements are being made. We all recognise that there is no meaning in the phrase "20 miles an hour" unless we state the point of reference with regard to which this velocity is to be measured. A man sitting in a railway carriage is at rest with regard to the carriage but he may be moving at twenty miles an hour with regard to some point fixed on the railway, and sixty miles an hour with respect to a point on a train moving at forty miles an hour in the opposite direction. The mode of regarding physical phenomena based on the above conceptions is called the Theory of Relativity, and it is divided into two departments, viz., the special theory of Relativity which deals with uniform motions only, and the general theory of Relativity which embraces motions of any kind. Broadly speaking, the Theory of Relativity is the hypothesis that only motions of bodies *relatively* to one another can enter into our statements of physical laws. Certain deductions of a remarkable nature have followed from this postulate, one, that a ray of light is bent when passing near a massive body, and this prediction has been verified by observations made on the apparent position of stars near the sun during a total solar eclipse. Since no observations have enabled us to determine the relative motion of the earth and the hypothetical æther, some Relativists have declared that we have no justification for assuming the existence of an æther. We have, however, certain facts before us which cannot be ignored. We know that the sun sends to the earth in the form of light and heat large quantities of energy and we know that this radiation takes about eight minutes to travel from the sun to the earth. We are therefore justified in asking, In what form or mode does this energy exist *after* it has left the sun and *before* it reaches the earth? We know also that energy is conserved and cannot (by us) be created or destroyed, and that therefore this energy is transferred from the sun to the earth. We are only able to imagine two methods by which this can be achieved, one, by the bodily movement of matter of some kind possessing kinetic or potential energy in association with it, and the other by a process of handing on energy in kinetic or potential form from point to point in a universally diffused medium.

The observed facts at our disposal do not enable us at present to decide finally by which of these methods radiant energy in the form of light

passes through space and the full truth as to the nature of light and of electricity is not yet in our possession.

There are certain phenomena in connection with photo-electricity or the liberation of electrons from atoms by light waves which are quite inexplicable on the assumption of a uniform distribution of the wave energy over the wave front of a beam of light, and seem more consistent with some kind of corpuscular theory of light.

Hence, although the hypotheses which we construct to enable us to view certain observed facts in consistent relation with each other are useful up to a certain point, they frequently need to be discarded or reconstructed as time goes by, and are useful only so far as they suggest investigations which lead to the permanent possession of important truths. The late Professor Huxley once said that the great and ever-recurring tragedy of science is that of a beautiful hypothesis killed by an ugly fact. But, although these ugly facts spring up in unexpected places and destroy our attractive hypotheses, they really serve a useful purpose in preventing the survival of the unfit.

The solid and valuable discoveries remain when theories and speculations have passed away.

CHAPTER VII

WIRELESS TELEGRAPHY AND TELEPHONY

No department of applied science has attracted greater public and scientific attention or made more remarkable progress of late years than wireless telegraphy and telephony.

The astonishing feats of communication over great distances, unconnected by any material link, effected by it excited curiosity, whilst the physical problems and questions involved have attracted the interest and engaged the thoughts of scientific men of the highest calibre.

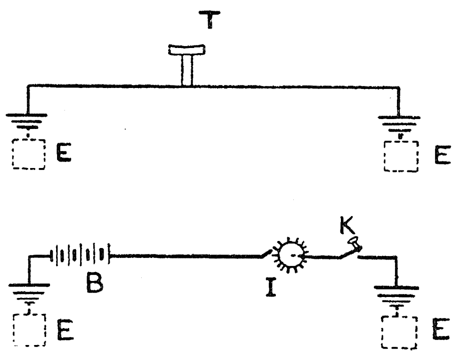


FIG. 1.—Earth Conduction Wireless Telegraphy. E, E are plates of metal sunk in the earth. B is a battery and I an interrupter, and K a key in one circuit, and T is a telephone in the other circuit. When the key K is manipulated so as to send out Morse signals, sound scorresponding thereto are heard in the telephone receiver T if the distance of the two circuits is not too great.

Modern wireless telegraphy is the outcome of the penetrating insight of Maxwell and his theoretical prediction of the possibility of creating electromagnetic waves in space, followed by the discovery by Hertz of a practical method of producing them, but it needed many special inventions to convert these scientific facts into an effective system of telegraphy.

The idea that it might be possible to communicate electrically between two places not connected by a wire is, however, as old as telegraphy itself.

We have seen in the introductory chapter that Steinheil, of Münich, in the very early days of wire telegraphy, found that the earth might be made to take the place of the return circuit, and he indulged the hope that some way would be found of dispensing with the wire altogether.

Morse showed in 1842, by experiments made in a canal at Washington,

U.S.A., that it was possible to interrupt a metallic electric circuit in two places in the lead and return wires and send the current through the water.

A few years later James Bowman Lindsay, of Dundee, a self-taught genius, rediscovered the same fact, but it was not until the invention of the telephone had provided a sufficiently sensitive instrument for the detection of feeble alternating currents that Trowbridge, in 1880, and later on Sir William Preece, in 1886 and 1887, were able to make any progress in this earth conduction type of wireless telegraphy.

If two plates are sunk in the earth at a distance from each other and connected either by an alternating current generator or a battery with an interrupter, alternating or intermittent currents will flow through the earth in widely diverging lines from one plate to the other. If two other plates are sunk in the earth at points not too far from the generator plates and in places differing in potential, and if these collector plates are connected by a telephone, a part of the current flowing through the earth will pass through the telephone circuit, and if the battery current is made and broken intermittently in accordance with the Morse code, signals may be transmitted in this way through the earth (see Fig. 1).

This method is called earth conduction wireless telegraphy. It was employed to a considerable extent during the European War of 1914–18 for communication between troops in the field under conditions when radio-telegraphy could not be used. The sensitiveness of the telephone was greatly increased by the use of modern thermionic amplifiers to be described presently, and hence the range over which the method was effective, compared with early experiments, was greatly increased. Another type of wireless telegraphy effective over a limited range is that called inductive telegraphy.

If two insulated wires are stretched parallel to each other at a distance, and if the ends of both are connected to earth plates, then the passage of an alternating current through one wire will create a feebler alternating current in the other wire by electromagnetic induction. If we insert a telephone in the circuit of one wire and a key for interrupting the alternating current in the other wire, we can start and stop the secondary induced current, and hence the hum or musical sound made by it in the telephone,

at pleasure by using the key (see Fig. 2). Hence we can transmit Morse code signals, and so communicate. This method was put into practice and investigated by Sir Oliver Lodge. This inductive telegraphy was combined with the conductive method by Sir William Preece and put into practice over short distances in a few places by the General Post Office.

It was, however, rendered antiquated by the subsequent invention in 1896 of the far more useful electric wave telegraphy.

It is interesting to note that this inductive method was in a modified way used during the great European War for the purpose of guiding ships into harbour or through mine fields.

An insulated cable is laid on the sea or river bottom, and the far end is connected to a metal plate laid in the water. An alternating current

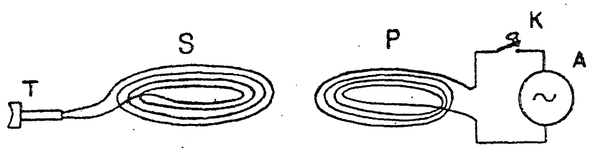


FIG. 2.—Magnetic Induction Wireless Telegraphy. P and S are two coils of wire and the circuit P contains a key K and alternator A. T is a telephone in the circuit S, and when Morse signals are made with the key K corresponding sounds are heard in the telephone.

is then sent through the cable from a generator placed on shore, and this current flows through the cable and enters the water by the plate, and then returns through the earth.

The ship to be guided is provided with two coils of insulated wire placed one on the port and the other on the starboard side below the water line. If a telephone is inserted in each of these coils, sounds will be heard in it as long as the ship steers along and near to the cable. If the ship deviates from this course, the sounds become fainter or vanish in one or both telephones. Hence a ship can by this means *feel* its way along the cable into a harbour or up a river, even at night or in fog, or through a mine field.

Both the above methods of wireless communication have a very limited field of operation compared with that of radio- or electric wave telegraphy.

This last-named method originated between 1894 and 1896. In Sir Oliver Lodge's lecture on "The Work of Hertz," delivered in June, 1894, at the Royal Institution of Great Britain, experiments were shown in which a coherer was affected by electric waves generated in a distant room. These experiments were also exhibited at Oxford in the same year.

No direct mention was made in these lectures of the application of Maxwellian electromagnetic waves to telegraphy, but the demonstrated power of an electric spark to influence a coherer at a distance must have turned the minds of ingenious persons to the utilisation of such waves

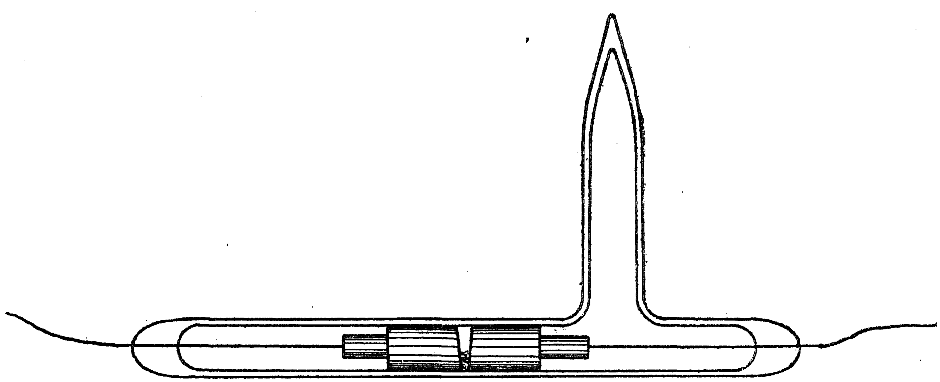


FIG. 3.—A Marconi Coherer.

for telegraphic purposes. Subsequently we were told that the matter had begun to occupy the thoughts of several well-known electricians, and, also, that Admiral Sir Henry Jackson had made a certain progress in confidential experiments for the Navy in this direction.

Nevertheless, it remains certain that the credit for the first definite accomplishment of telegraphy by electromagnetic waves belongs, above all, to Senatore G. Marconi, who in 1895 made the inventions connected with it which transformed small-scale experiments with electric waves into a practical method of telegraphy over long distances. He had the necessary means and high abilities to persevere with the work of invention until a really useful stage was reached (see Plate 1, page 312).

It is interesting to note that Sir William Crookes, in an article in the

Fortnightly Review for February, 1892, had made a strikingly correct forecast of the coming of this electric wave telegraphy based on certain experiments by Professor D. E. Hughes, made as far back as 1879, and shown to many scientific men.*

Professor Hughes had at one time made a microphone consisting of metallic filings enclosed in a glass tube and placed in series with a battery and a Bell telephone receiver. He appears to have noticed that such an arrangement was sensitive to electric sparks at a distance.

He was discouraged from continuing these experiments by the opinion of an eminent physicist to whom he showed them, but if he had persevered there is little doubt that he would have anticipated the discoveries of Branly and Lodge with regard to the coherer, and might even have been regarded as a pioneer in radio-telegraphy itself.

Marconi began his work by making an improvement in the Branly-Lodge coherer. He employed an extremely small quantity of nickel and silver filings placed between two silver plugs, these being connected to platinum wires sealed through the ends of a glass tube carefully exhausted of its air (see Fig. 3). This little agglomeration of metallic filings in a loose condition has a feeble conductivity for the current from a single voltaic cell. If feeble electric oscillations are passed through it, the filings cohere and conduct electricity better, and will then pass sufficient current from a single voltaic cell to operate a telegraphic relay.

To bring these filings back to a non-conductive condition Marconi adopted and improved the method used by Popoff and Lodge of tapping the tube by an electromagnetic tapper like the mechanism of an electric bell with the gong removed (see Fig. 4). But he introduced many ingenious devices for exactly adjusting the blow, and he mounted the whole arrangement of coherer, tapper, relay and batteries in a metal box, to shield it from the action of stray electric waves. His especial and important inventive contribution was that of the earthed aerial wire.

The earliest appliances he devised for radiating and detecting telegraphic signals by electric waves were, then, as follows :—At the sending and receiving stations he erected long, nearly vertical, wires supported by an insulator at the upper end from a mast or tower. These are called

* See a letter by Professor D. E. Hughes in the *Electrician*, May 8th, 1899, vol. 43, p. 40.

aerial wires or aerials. At the transmitting end he attached the lower end of the aerial to one of a pair of metal spark balls placed very near together. The second ball was connected to a metal plate sunk in the earth or laid upon it. The balls were connected to the secondary terminals of an induction coil, and in the primary circuit of the coil was placed a telegraphic signalling key, to break and make the circuit (see Fig. 5).

Marconi thus constructed a very large Hertzian oscillator or radiator,

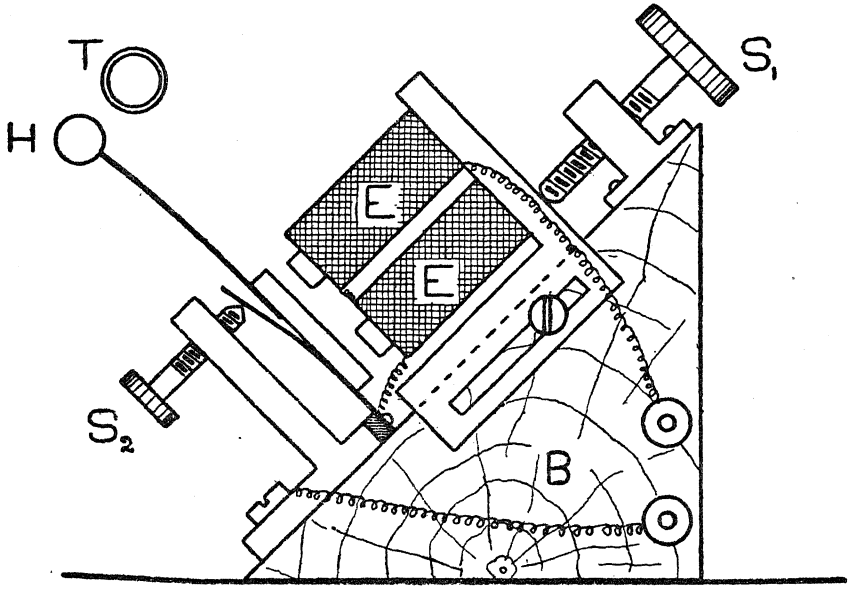
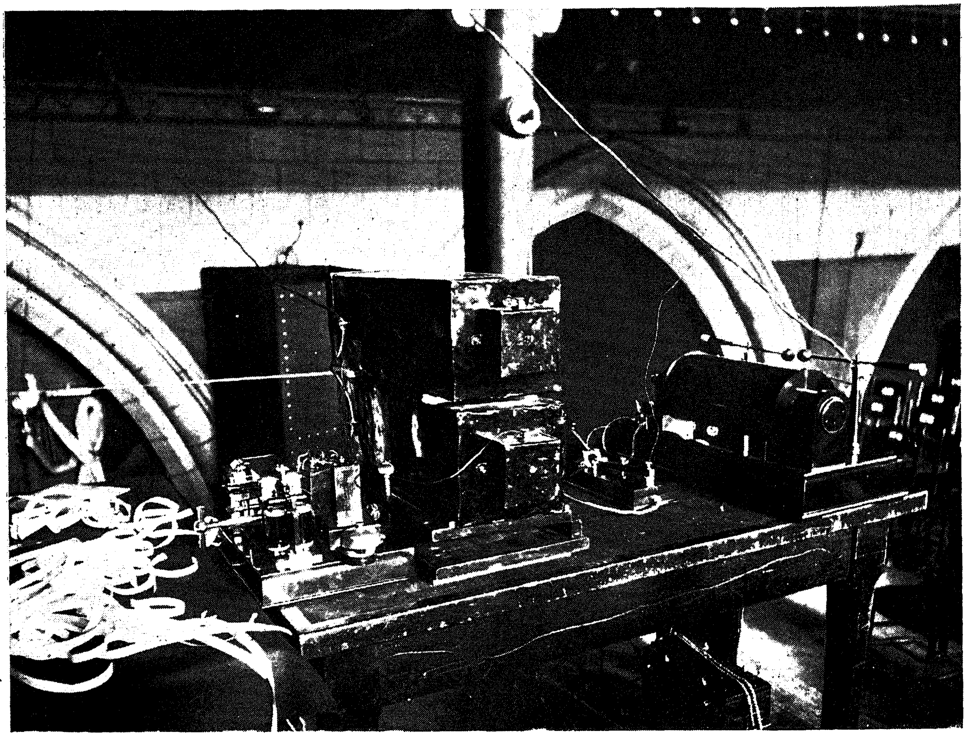


FIG. 4.—Tapper used by Marconi to tap back the Coherer Tube T (shown in section) to a state of non-conductivity. E is an electromagnet and H a vibrating hammer like that in an electric bell.

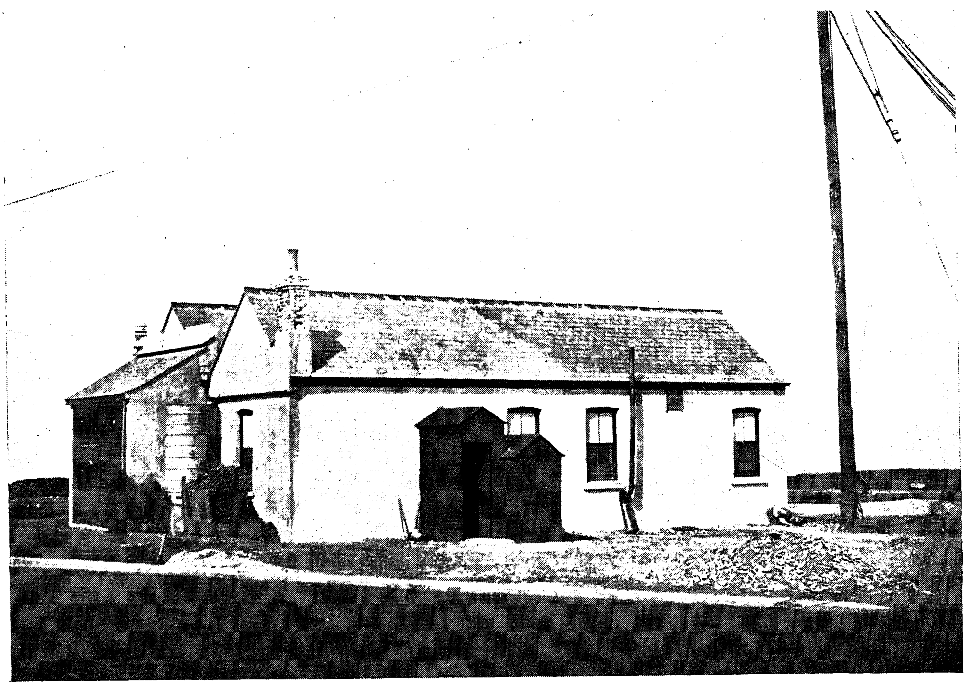
one half of which was the aerial wire, and the other half the plate buried in the earth. The aerial wire forms with the earth a sort of condenser or Leyden jar, of which the inner coating is the aerial wire, and the outer one the earth.

When the coil is in action this condenser is rapidly charged and discharged across the spark gap with electric oscillations, and the result is that very high frequency electric currents run up and down the wire. These currents create in the æther or electromagnetic medium electro-

PLATE 3.

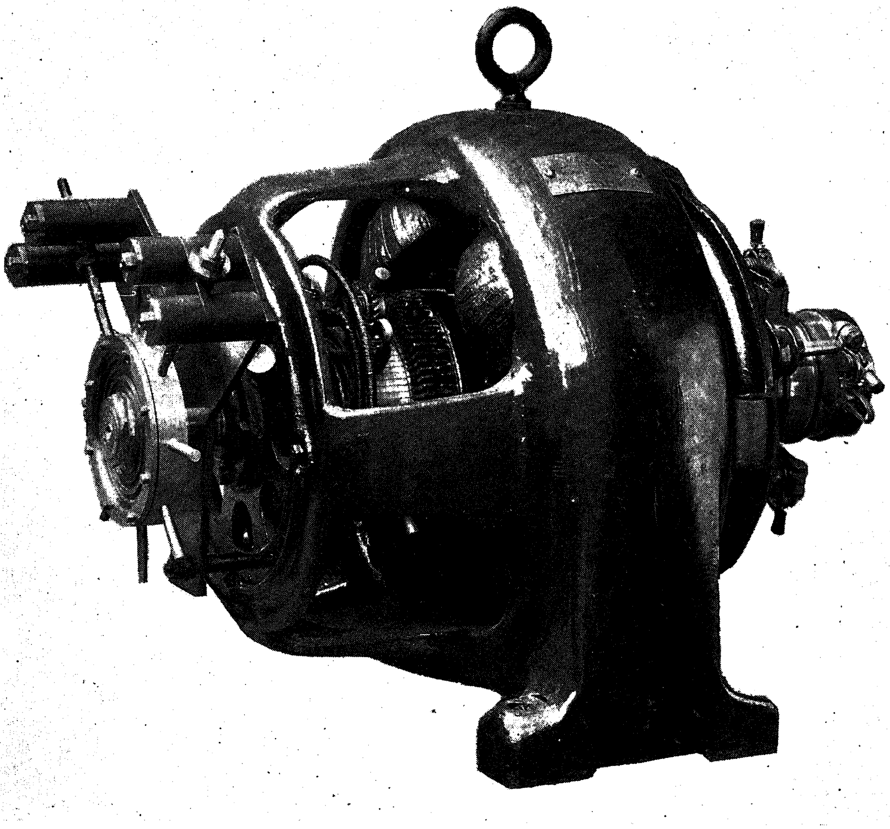


Apparatus for the reception of Wireless Messages from France by the Marconi System erected on the Author's lecture table at the Town Hall, Dover, for a lecture by him on "The Centenary of the Electric Current," before the British Association, September, 1899. (See page 317.)



The first Long Distance Wireless Station erected at Poldhu, Cornwall, England, for Transatlantic Wireless Telegraphy. (See page 319.)

Interior of the first Long Distance Wireless Station on the Marconi System at Poldhu, showing part of the plant first installed.



[*By permission of Marconi's Wireless Telegraph Co., Ltd.*

An Alternator with Marconi Rotating High-speed Discharger on the Shaft as used in Wireless Telegraphy. (See page 323.)

[*To face page* 313.

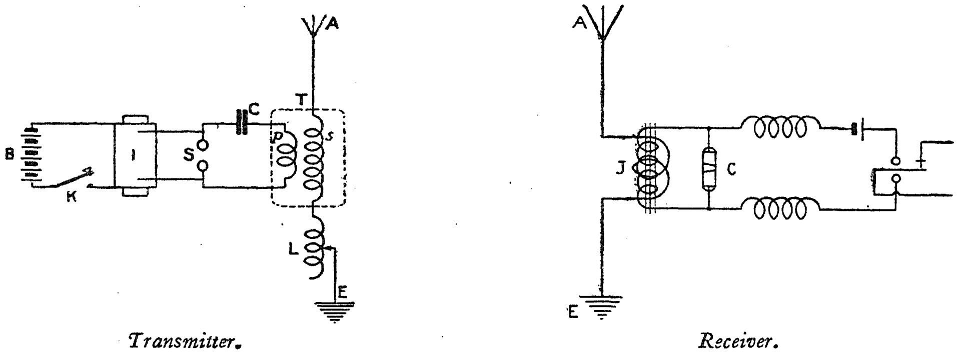


FIG. 5.—Early form of Marconi's system of Electric Wave Telegraphy. B is a battery supplying current to an induction coil I with a key K in the primary circuit of the coil. When the coil is in action the condenser C is charged and then discharged with oscillations across the spark gap S. This creates oscillations in the aerial A and radiates trains of electric waves. The receiving aerial picks these up, which then act on the coherer C (right-hand), and this permits the local battery to send a current through the coherer and the relay and operates a Morse inker. This method of reception is now antiquated and no longer used.

magnetic waves, which spread outwards from the aerial just as, when a stone is thrown on to still water, it sends out expanding circles of ripples centred on the point where the splash is made.

In the case of the aerial these expanding rings are lines of magnetic

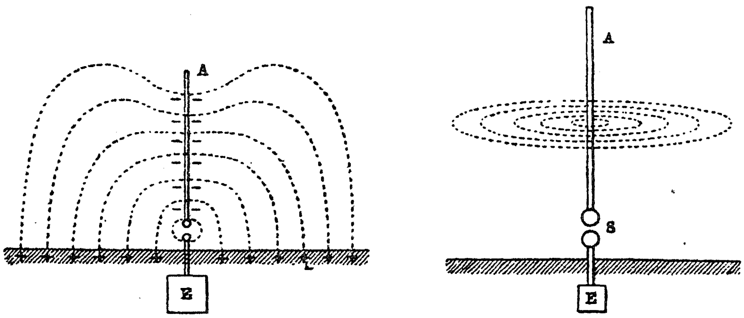


FIG. 6.—Lines of Electric Force (left-hand diagram) and of Magnetic Force (right-hand diagram) round a Plain Aerial Wire. These sets of lines are actually superposed but are drawn separately for the sake of clearness.

force, and perpendicular to these and to the earth's surface there are a series of lines of electric force (see Fig. 6).

This double system of lines of magnetic and electric force moving outwards from the aerial constitutes an electromagnetic wave. At inter-

vals, called a wavelength, these forces are at a maximum value and at intermediate points are also a maximum, but reversed in direction. At points halfway between a maximum value in one direction and in the opposite they have zero value and graduate both ways from zero to a maximum (see Fig. 7).

Each time the aerial is charged by the induction coil and discharged across the spark gap a group of gradually decaying oscillations is produced

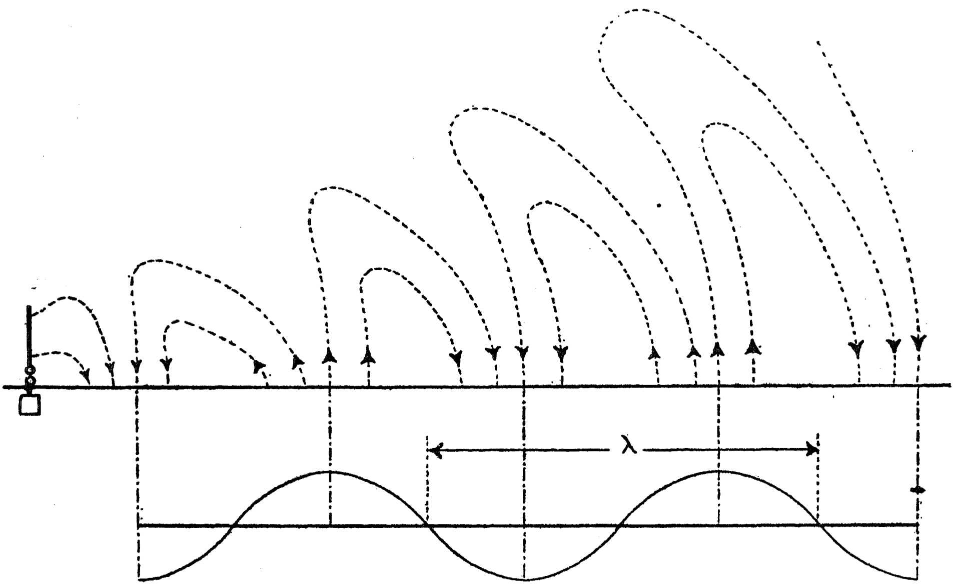


FIG. 7.—A Diagram illustrating the manner in which Semi-loops of Electric Force represented by the dotted lines move away from a Wireless Aerial represented by the short black line. The wavelength is the distance from crest of one loop to that of the next loop.

in the aerial called a *train* of oscillations. The interval of time which elapses between a movement of the electricity in the aerial wire, say, upwards, and a succeeding similar movement is called the *periodic time*, and the reciprocal of this is called the *frequency*. Thus, the periodic time may be one-millionth of a second and then the frequency is one million.

The wavelength of the electric waves sent out from the aerial is the distance, measured in feet or metres, from a point where the magnetic

or electric force in space has a maximum value to the next adjacent place where it has a maximum in the same direction. The wave or system of lines of force moves outwards from the aerial with the same velocity as light, viz., 300,000 kilometres or 186,000 miles per second (see Fig. 7). There is a close connection between this wavelength and the frequency of the oscillations in the aerial, for the wave travels a distance of one wavelength in the periodic time. Hence, the product of the wavelength and the frequency gives us the wave velocity. The velocity of light is very nearly 1,000 million feet per second. Hence, if we know the frequency of the oscillations in the aerial, say, one million, we know that the wavelength must be 1,000 feet.

As already stated, at each spark discharge of the coil a group of waves is sent out, all of the same wavelength, but gradually decreasing amplitude, and this group of die-away waves is called a *wave train*. Waves of this character are called *damped* waves. As many wave trains are emitted per second as there are sparks, and these may be anything from 50 to 500 per second.

It is necessary, therefore, to distinguish between the frequency of the oscillations and the frequency of the trains of oscillations.

The signals are made by closing the key in the circuit of the induction coil for a brief instant to make a Morse *dot* or for about three times as long to make a Morse code *dash*, and thus letters can be signalled. At each dot a few wave trains are emitted by the aerial and at each dash a longer series of wave trains. These wave trains flit away in all directions with the speed of light waves.

Turning then to the receiving system, we have there a similar aerial wire, and in his earliest experiments Marconi connected his coherer between the bottom end of this aerial and an earth plate. When the waves from the transmitting aerial strike the receiving aerial the lines of magnetic force of the wave cut across the latter, and just as in the case of the dynamo this "cutting" produces in the receiving aerial a feeble high-frequency, alternating, electromotive force, because the groups of circular lines of magnetic force in the waves which cross the aerial are, as already explained, arranged first pointing in one direction and then in the opposite.

Accordingly, the passage across the receiving aerial of a wave train or group of wave trains causes the coherer filings to be traversed by high frequency oscillations and they, therefore, pass into a conductive condition and allow the current from the local voltaic cell to pass through them and through a telegraphic relay, which in turn is used to operate a Morse printing telegraph. A brief tap on the sending key, therefore, causes a *dot* to appear on the Morse paper tape at the receiving end, and the tapper at once acts and brings back the coherer filings to the non-conductive condition. If the key is held down for a longer time to make a *dash*, then the coherer is kept in a conductive condition as long as the oscillations pass through it, and we have a dash recorded on the tape. Hence, Morse code signals can be sent and intelligible messages transmitted. Marconi put this method of wireless telegraphy in operation in 1895 on his father's estate at Villa Griffone, near Bologna, Italy, and in 1896 came to England, where he filed an application for a British patent (No. 12039 of 1896) for his invention, and introduced it to the notice of Sir W. Preece, then Engineer-in-Chief of the British Post Office Telegraphs. He made various successful demonstrations of it and in 1898 established two stations, one on the Isle of Wight and the other at Bournemouth, about twelve miles apart. Here the author was kindly given the opportunity to see it in operation at Easter, 1898, and many others, such as Lord Kelvin, were greatly interested in it. In 1899, Marconi made the improvement of connecting the terminals of the coherer to the secondary circuit of a small transformer, the primary circuit of which was inserted between the base of the receiving aerial and the earth plate.

In March, 1899, he erected two aerials, one at the South Foreland Lighthouse, near Dover, and the other at Wimereux, near Boulogne, in France, and transmitted messages across the English Channel by electric wave wireless telegraphy. This feat attracted great public attention, and the chief daily papers sent their reporters to examine and describe it. The author wrote a letter to *The Times*, published on April 3rd, 1899, pointing out the great practical value of this achievement in enabling instantaneous communication to be established between lightships or lighthouses and the shore.

The East Goodwin Lightship had already been provided with Marconi apparatus, and a few weeks later, during a dense fog on April 28th, 1899, a steamer, S.S. *R. F. Matthews*, ran into it and inflicted serious damage. But the Lightship was able at once to communicate with the South Foreland Lighthouse and obtain assistance.

In September, 1899, the British Association met at Dover, and at the suggestion of the author an exhibition was made during the week of the Marconi system in operation. The author was invited to give an evening public lecture, and that year being the centenary of Volta's invention of the voltaic cell, he chose for his subject, "The Centenary of the Electric Current." During the lecture telegraphic communication was effected by this electric wave telegraphy with the French Association for the Advancement of Science, meeting at the same hour at Boulogne, and messages were exchanged by Marconi wireless telegraphy with great interest to a distinguished audience (see Plates 2 and 3, pages 312 and 313). An extensive practical trial of this wireless telegraphy took place the same month at the British naval manœuvres with pronounced success.

In 1897, Sir Oliver Lodge applied for patent protection for important improvements in syntonic wireless telegraphy, in which he pointed out the importance of "tuning" in connection with the appliances.

Every electric circuit possessing capacity for electricity and inductance or electric inertia has a natural time period in which the electric charge vibrates when it is disturbed, just as a pendulum has a natural time period of oscillation under gravity depending on its length.

If two circuits have the same natural time period they are said to be in syntony or in tune with each other.

If electric oscillations are taking place in one circuit, these will very easily excite sympathetic oscillations in an adjacent circuit tuned to the first, but not otherwise.

Hence it is clearly necessary that the receiving system in wireless telegraphy should be tuned to the transmitter and also that the latter should emit long trains of waves comprising many oscillations. This enunciation of the principles of *syntonic* or tuned wireless telegraphy proved to be fundamental in importance.

The defect of Marconi's early arrangements was that the plain aerial

with spark balls at the base did not store up sufficient energy to produce long trains of many waves. It got rid of its small energy almost in a couple of vibrations. The receiving aerial was also non-syntonic and able to pick up signals from any other source of electric waves.

In 1900 Marconi made another great step forward, disclosed in a British Patent Specification, No. 7777 of 1900. In this modification his transmitter comprised a battery of Leyden jars, and one single loop of thick wire interrupted by a spark gap connected their two coatings.

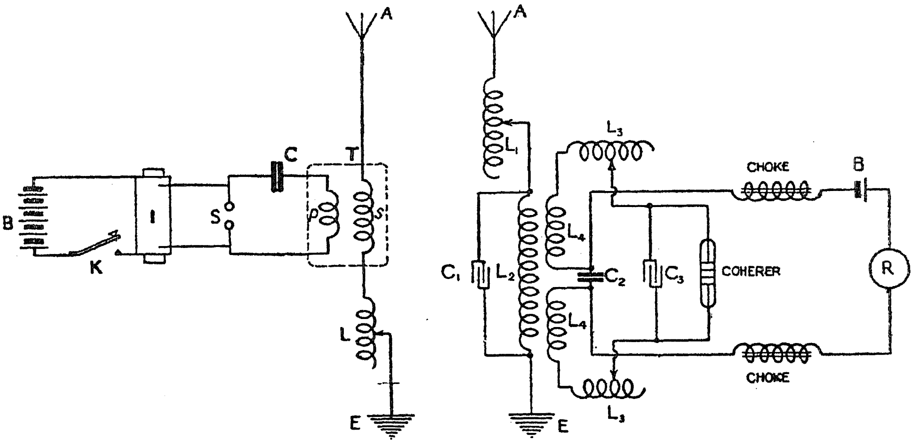


Fig. 8.—Scheme of arrangement of Circuits for Marconi's system of Syntonic Wireless Telegraphy. The transmitter is shown on the left-hand side and the receiving circuits on the right. A, A are the aerial wires, B the battery, S spark gap, I induction coil, K signalling key, R is the relay which operated a Morse ink recorder, C, C_1, C_2 are condensers, and T is the transmitting transformer.

Over this single loop of wire was wound a secondary circuit of several turns, of which the two ends were connected respectively to the aerial wire and to the earth plate, a coil of a variable number of turns, called a tuning inductance, being interposed (see Fig. 8). The spark balls were connected to the secondary circuit of an induction coil capable of giving a spark of several inches in length. When this coil was set in operation, it charged the Leyden jars, and they then discharged with powerful prolonged trains of oscillations across the spark gap and through the single loop of wire. If the circuit of the aerial wire was properly tuned to the frequency of these oscillations, then strong sustained

vibrations were set up in it, and long trains of waves radiated from the aerial.

At the receiving end Marconi also arranged a similarly tuned circuit, so that it was not easily set in vibration by the impact of a solitary wave, but only by the arrival of a prolonged train of many waves of suitable frequency.

This system of syntonic telegraphy gave far more range of communication and privacy, and very soon wireless messages were being sent by it over distances of several hundred miles over sea.

The patent in question was the subject of a good deal of litigation, but was supported by the courts as covering a fundamental invention.

This system of radio-telegraphy was generally called a spark system, because it involved the spark discharge of a condenser.

In January, 1901, Marconi employed the above method in sending wireless messages from St. Catherine's Lighthouse, in the Isle of Wight, to the Lizard, in Cornwall, a distance of about 200 miles.

This success encouraged him to make an attempt to bridge the Atlantic with electric waves.

It was obvious that much greater power would be required, probably far beyond that capable of being supplied by such an induction coil as had been used in previous experiments. A convenient site for the first high-power radio-telegraphic station was secured by him at Poldhu, near Mullion, in Cornwall, and the erection of appropriate buildings commenced in October, 1900 (see Plates 3 and 4, page 313). The author was entrusted with the duty of specifying for the power plant. In place of an induction coil worked by a voltaic battery it was necessary to employ an alternator driven by a 25-h.p. oil engine, and high-tension transformers raising the voltage to 20,000 volts.

The author designed a type of condenser consisting of sheets of glass coated on both sides within an inch of the edge with thin sheets of tin or zinc. A number of these were immersed in a stoneware vessel filled up with linseed or resin oil.

The spark balls were at first merely large fixed balls, but later on the author designed a type of discharger consisting of two metal disks or balls kept in slow rotation by an electric motor.

A number of masts about 200 feet in height were erected to support the aerial wires, composed of fifty wires arranged in fan-blade form.

The arrangements having been made, Mr. Marconi left England with his assistants, Mr. Kemp and Mr. Paget, at the end of November, 1901, and stationed himself at St. John's, Newfoundland. He took with him

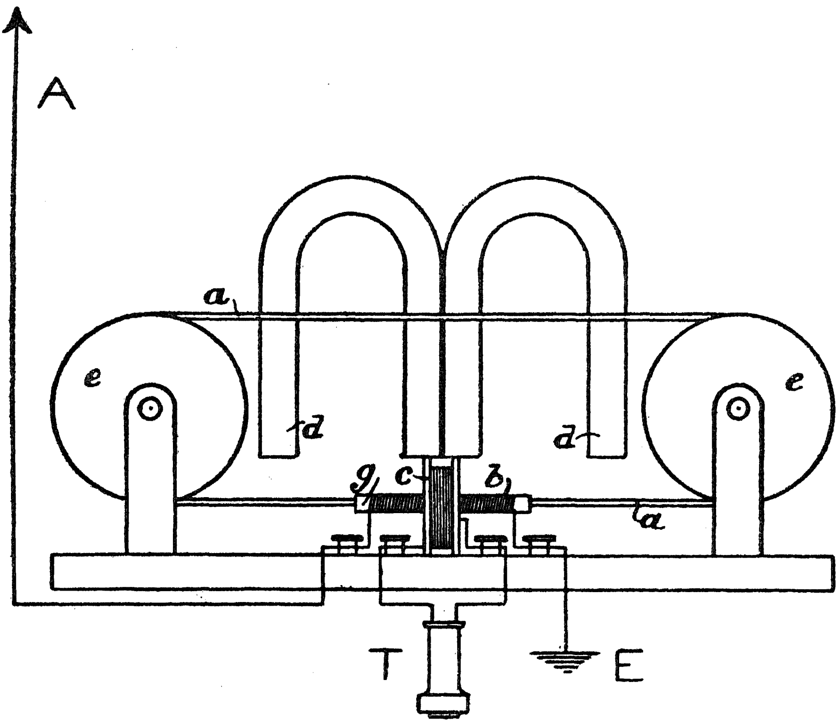


FIG. 9.—Marconi's Magnetic Detector of Electric Waves. *a* is the iron wire band, *e*, *e* the two pulleys kept in rotation by the clockwork, *d*, *d* the two magnets, *b* is the coil through which the electric oscillations pass, *c* is the secondary coil and T is the telephone receiver. A is the aerial wire.

kites and balloons, to elevate a temporary receiving aerial wire, and after some difficulties were overcome, he was able on December 13th, 1901, to report that he had received signals in the form of the letter S, – – – (three dots), which were certainly sent out from the Poldhu station.

This transmission caused very great public interest, and especially so in scientific circles, because it was not at all clear to physicists why these

long electromagnetic waves should follow round the earth's curvature or be diffracted over a distance of 2,200 miles. It is impossible within the limits of this chapter to follow out in detail the gradual development of long-distance radio-telegraphy. It will be found recorded at great length in the author's book, *The Principles of Electric Wave Telegraphy* (Longmans, Green & Co., London). Suffice it to say that, when once it had been proved that electromagnetic waves having a wavelength of 2,000 or 3,000 feet could be propagated across the Atlantic, attention began to be directed to improving the appliances and quickening the signalling, so as to make possible commercial work.

Mr. Marconi invented in 1902 an ingenious form of magnetic detector. It had been known for nearly a century that Leyden jar discharges could magnetise steel needles when sent across them, but in 1895 Sir Ernest Rutherford showed that quite feeble electric oscillations could demagnetise bundles of very fine steel wire, if the oscillations were sent through a coil of wire wound spirally round the bundle. He employed Hertzian waves to set up oscillations in a receiving wire at a distance of about half a mile from the transmitter, and proved that the exceedingly feeble oscillations so produced in the receiving aerial could demagnetise small bundles of magnetised steel wire.

Marconi constructed his magnetic detector with an endless loop formed of many fine iron wires bound together (see Fig. 9). This loop was placed over two pulleys, and made to revolve slowly by clockwork. It passed in front of the poles of a pair of horseshoe-shaped permanent steel magnets, and that part of the wire was embraced by two spiral coils of wire. One of these coils was in the circuit of the receiving aerial wire, and the other was connected to a Bell receiving telephone. When electric waves fall on the aerial they create high-frequency oscillations in it and in the little coil of wire embracing the moving iron band. This facilitates its magnetisation, and the sudden increase of it results in the production of an induced electric current in the telephone coil and a sound like a tick in the telephone. This sound is repeated as each wave train falls on the aerial, and these little ticks run together into a musical note if the spark frequency is anything above 100. The cutting up of the wave trains into short or long periods by the transmitting key results in the

production of audible Morse Code signals in the telephone. The receiving operator can wear a pair of telephones against his ears held on a steel band, and, with his hands free, can write down the Morse letters as he hears them. The ear is more automatic than the eye, and this mode of taking down telephone signals by ear and hand converts the operator into a kind of human relay, quick and certain in its action.

By this ear-reception it became possible to receive signals at the rate of about 150 letters a minute.

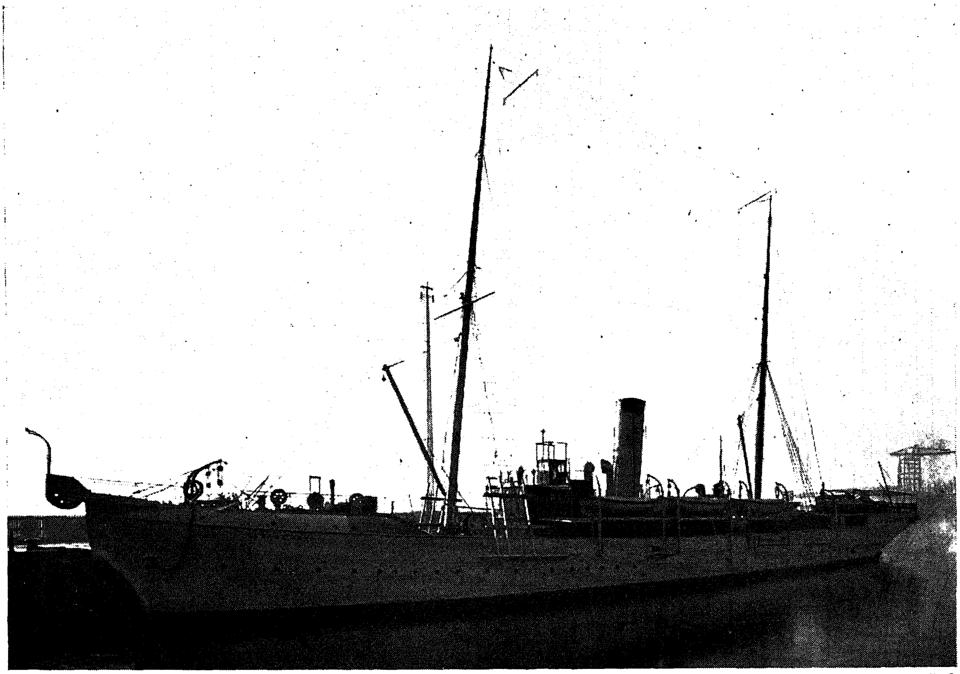
As soon as electric wave or radio-telegraphy began to be practised it was found that the waves travelled better over sea than over dry land, and that in some cases there was very considerable absorption of the wave energy in passing over dry land. Furthermore, it was found that for long-distance transmission a wave of great wavelength was necessary. Hence, whereas in the early days a wavelength of about 1,000 feet was employed, and is so still for short-distance transmission, yet for long-distance working the wavelengths have been increased until, now, 20,000 or even 50,000 feet are used. This means to say that the distance from crest to crest of the successive electric waves is from four to ten miles.

Another obstructive effect which presented itself very early was that due to atmospheric electric discharges. At certain periods of the year there are thunderstorms, and even at all times, especially at night, there are vagrant electric waves travelling through the atmosphere which are set up either by distant thunderstorms or else by silent atmospheric discharges, or due to cosmic actions.

These disturbances are called "atmospherics," and they cause false signals and produce disturbing sounds in the receiving telephones of wireless apparatus. From the very beginning they have been the bugbear of radio-telegraphy, because an extra dot or two thrown into a Morse code letter quite alters its meaning. Since most commercial messages are sent in secret codes there is no possibility for the operator to guess what the letter ought to be from the context. Thus an extra dot converts an S (– – –) into an H (– – – –) or a U (– – ——) into a V (– – – ——) and so on.

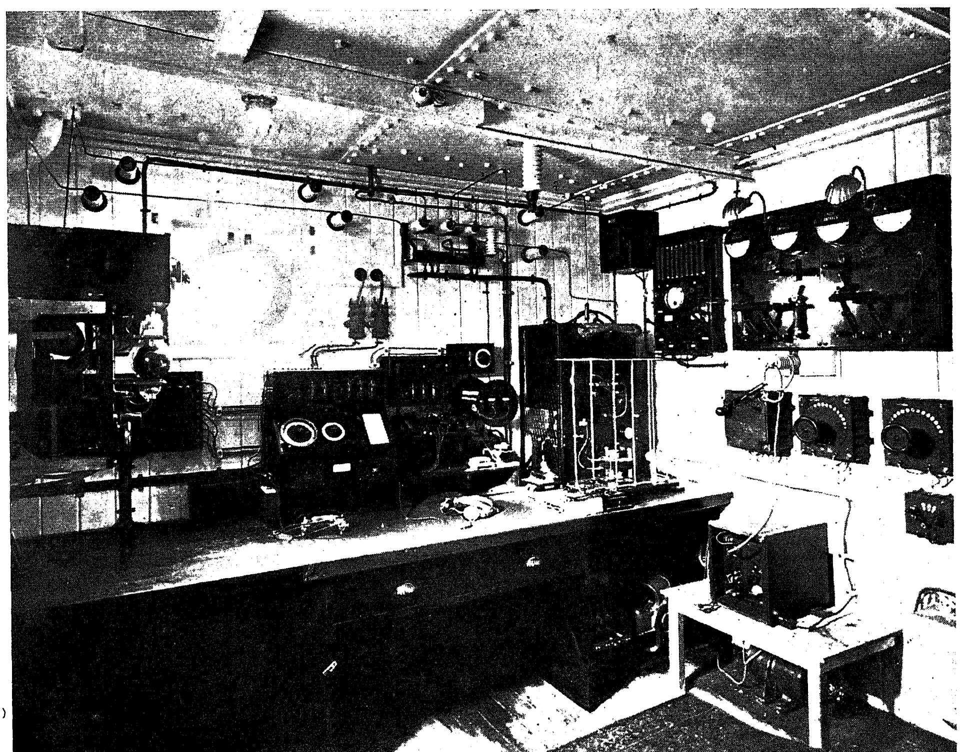
One way in which these atmospherics have been nullified is by the invention of the musical spark or high frequency discharger. In an

PLATE 5.



[By permission of Marconi's Wireless Telegraph Co., Ltd.

A Ship fitted with an Aerial Wire between the two Masts for sending and receiving Wireless Messages.

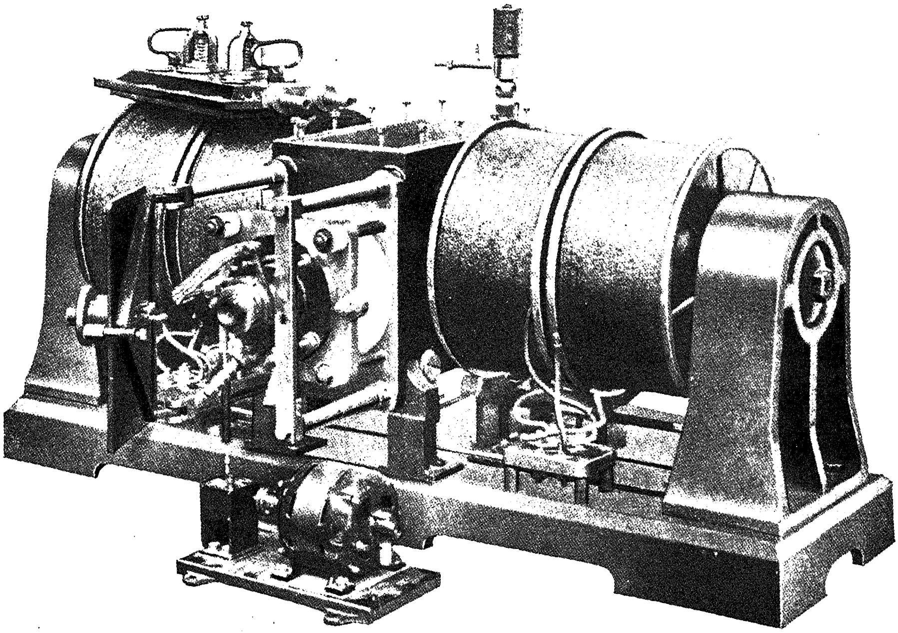


[By permission of Marconi's Wireless Telegraph Co., Ltd.

The Interior of a Ship's "Wireless Cabin" equipped with Apparatus for sending and receiving Wireless Messages.

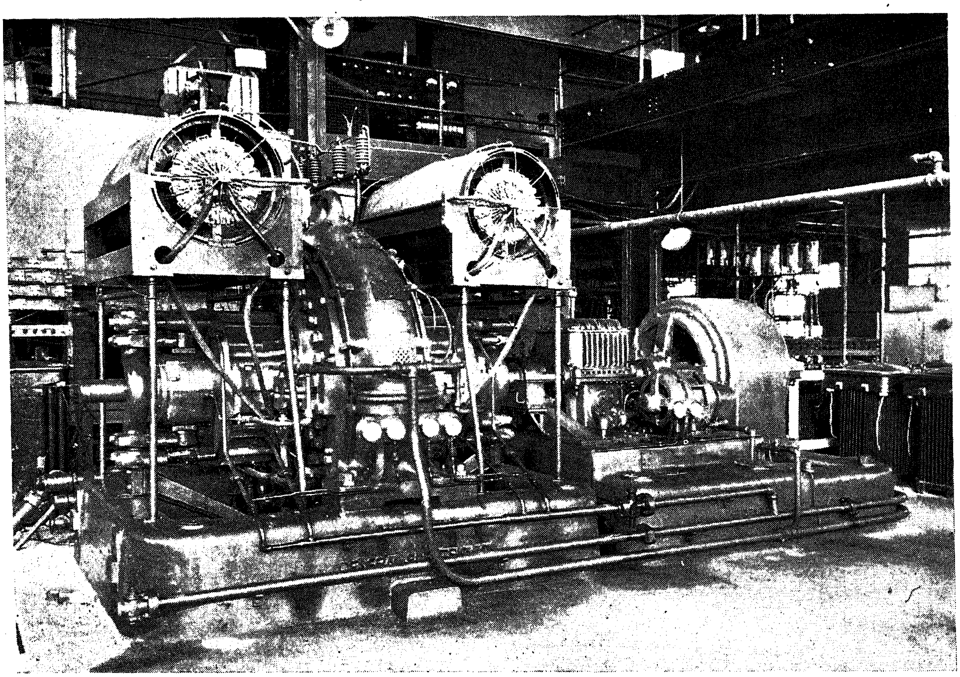
[To face page 322.

PLATE 6.



[Reproduced from the "Wireless World."

A Poulsen Electric Arc Generator of Continuous Electric Oscillations. The arc is formed in a box full of alcohol or petrol vapour between the poles of an electromagnet.



[By permission of the Radio Corporation of America.

Alexanderson High-frequency Alternator, 200 kilowatt size. The alternator (on the left hand) is driven by an electric motor (on the right-hand side of the view).

[To face page 323.

ordinary induction coil the break or vibrator interrupts the primary current only about fifty times a second or so. Hence, the spark frequency is low and, therefore, the pitch of the note heard in the receiving telephone is low also. The false sounds or waves set up by the "atmospherics" are therefore not easily distinguished from the signalling sounds or message signals. It has been found that if the discharges of the condenser are made very rapidly and uniformly, say 300—700 a second, then the sounds heard in the telephone due to this have a high musical note and the signals are easily distinguished from the sounds due to atmospherics. Again, the ear and the telephone are most sensitive to a note of about 500 frequency. This means that at such a frequency less current through the telephone will make an audible sound than at any other frequency. These musical sparks are now produced by a discharger which consists of a disk having spokes or studs on its circumference. The ends of these spokes pass very near to two fixed studs, so that on passing the condenser circuit is completed and the discharge takes place. The disk is generally driven by being attached to the shaft of the alternator, which supplies the charging current (see Plate 4, page 313, lower diagram).

Senatore Marconi invented one form of this studded disk discharger in 1907, especially for use in long distance stations. It has the additional advantage that the great draught of air produced by the whirling disk blows out any electric arc which starts between the discharge points due to current coming directly from the transformer, but it does not extinguish the discharge coming from the condenser.

The result of these various inventions was to put radio-telegraphy on the spark system on a thoroughly practical basis especially for oversea intercommunication. Long before this date Marconi's Wireless Telegraph Company had established a large number of radio stations on the coast of Great Britain and other countries, and German and French radio companies had done the same. Ships in large numbers had been equipped with the apparatus, and communication was easily carried out over 300 or 400 miles. All the principal navies in the world began to employ it for signalling purposes (see Plate 5, page 322).

International conferences took place in Berlin in 1903 and 1906, and London in 1912, at which ocean radiotelegraphy was made the subject

...ssed against ...espite the ...us tne German ...u landing. Reuter

...ITUARY.

...is announced of Mrs. Corn-...est.—Reuter

MESOPOTAMIAN ENGAGEMENT

Mr. Churchill in the House of Commons today stated that the relief column advancing in Mesopotamia is engaged with 2000 Arabs near Fumeita. The situation in the Samara area has improved. The tribesmen are suffering heavily and there are signs of dispersal.—Reuter

...d, ...98; ...on on

...eter, Faulkner, ...C. today in their Engineers.--Reuter

...CING RESULTS.

...Molyneux Plate, 1st Racket, ...nd Tut tut, ten ran. Betting ...to 4, 4 to 1

...verpool Cup.—Probable starters and jockeys. Targiers (Hulme); Rich Gift, (Slade), Midshipmite (Whalley), Perion (J Bullock), African Star (L. B. Balding), A L Ordre (Blank), Alasnam (Fox); Devizes (Garnett), Red Head (Weston); Cumberland (T Morgan)

LOOKING BACKWARDS

JULY 22—IN OTHER YEARS.

1298—Battle of Falkirk: Wallace defeated.

1562—Birth of Robert Southwell, Jesuit poet who was hanged at Tyburn, February 22nd, 1595.

1914—Austrian ultimatum to Serbia shown to King of Rumania, 1914.

...ul defend ...ception can ...ne part of the

...N BELFAST.

...TIES IN STREETS ...SHIPYARDS.

...ersons were killed and eighty ... including forty seriously, during ...ghting between the Unionists and ...einers in the shipyards and streets of yesterday.—Reuter.

A Reuter message at six p.m. this evening states that rioting was renewed in Belfast today. The Post Office was wrecked. More soldiers and several civilians were wounded as the results of firing.

It was stated in the House of Commons this afternoon that considerable military forces were in the city. One of our ablest Generals was on the spot, and he would endeavour to keep order regardless of the political or religious views of any person concerned.

TRAINLESS DUBLIN.

With the exception of the Killarney express, not a single train left Dublin again today because police were aboard. Crowds for the Curragh races were again held up.—Reuter.

WIRELESS RATES TO SHORE.

Radio-telegrams may be transmitted from the *Victorian* through its special Marconi long-distance apparatus. The charge to the United Kingdom is 10½d. per word. The Postmaster-General has agreed to a special Press rate of 5½d. per word for Press messages sent, during this voyage only, to newspapers within the United Kingdom. All radio-telegrams should be handed to the Purser.

TO-MORROW'S SPORT.

CRICKET

SURREY *v.* LANCASHIRE.
WARWICKSHIRE *v.* HAMPSHIRE.
ESSEX *v* SOMERSETSHIRE.
KENT *v* NORTHAMPTONSHIRE
YORKSHIRE *v* GLOUCESTERSHIRE.
ROYAL ARTILLERY *v* ROYAL ENGINEERS, at Lord's.

RACING

LIVERPOOL MEETING (third day).
HURST PARK Henry VIII Plate T.Y.O

FIG. 10.—Sample Sheet of a Newspaper published on board Atlantic liners giving the chief news of the day by wireless telegraphy.

of regulations subsequently ratified and made legal by all the principal nations of the world.

Also legislation was introduced to regulate and prevent interference so that the use of the æther has become the subject of strict legal enactments.

In 1910 the coast radio stations established by the Marconi Company were taken over by the General Post Office and extended. It then became possible to communicate with ships on the high seas from any post office in Great Britain.

Moreover, the chief Atlantic liners were able to obtain a daily service of news and some of them actually published on board daily newspapers which gave the current news, such as the *Cunard Daily Bulletin*, first published on the R.M.S. *Campania* in 1904 (Fig. 10).

The greatest services to humanity were, moreover, rendered by this marine radiotelegraphy in cases of collision, fire or shipwreck.

Thus the White Star liner S.S. *Republic* collided with the S.S. *Florida* in 1909, in the Atlantic Ocean, but by means of radiotelegraphy assistance was obtained in time and all the passengers and crew of the vessels were rescued.

No such happy exemption accompanied the terrible tragedy of the loss of the White Star liner *Titanic* on her maiden voyage across the Atlantic Ocean with 2,000 persons on board. On April 4th, 1912, she collided with an iceberg and sank in four hours.

The S.S. *Carpathia* picked up seventy miles away the *Titanic's* calls for help and was able to arrive in time to rescue 711 persons from a watery grave, who would otherwise have without doubt perished with the 1,513 who were actually lost.

It is impossible exactly to state how many lives have thus been saved in the last twenty years by this wonderful invention, but it would probably be well within the mark to say that at least 5,000 persons owed their rescue from death by drowning to its beneficent aid even before the beginning of the Great War in 1914.* Thousands more were saved by its aid during the continuance of the German submarine attacks on vessels of the mercantile marine between 1914 and 1918.

* Even in January, 1911, Senatore Marconi estimated that at least 3,000 lives had at that time been saved by wireless telegraphy from shipwreck (see the *Evening News*, January 11th, 1911).

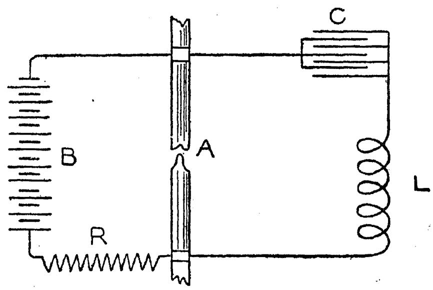


FIG. 11.—Duddell's Experiment of the Singing Electric Arc. A is the electric arc formed between solid carbon rods by current from a battery B. C is a condenser and L is an inductance coil in which oscillations are produced.

We must turn, then, to consider further advances.

It was very soon recognised that the general use of radiotelegraphy necessitated means for rendering any particular receiver sensitive only to waves of one particular wavelength.

In the earliest days of the art the receivers and transmitters were non-syntonic. Any transmitter affected almost every receiver within its range. The enunciation by Sir Oliver Lodge of the correct principles of syntonic telegraphy, and the invention by Senatore Marconi of suitable syntonic receivers and transmitters made a considerable improvement.

In 1903 the author was permitted to make a series of tests at the Marconi station at Poldhu, in Cornwall, which definitely proved that the powerful electric waves sent out from that station did not interfere with the working of ship-to-shore apparatus employing shorter waves even when the two installations were in close contiguity (see a letter to *The Times* by the author, April 14th, 1903).

The degree of difference in wavelength which must exist in order that a certain receiver may not be disturbed by an adjacent transmitter depends on several things, but chiefly upon the number of waves in a wave train, or, as it is called, upon the damping of the transmitter.

If we employ transmitters giving out wave trains which have only a few rapidly decadent waves in them,

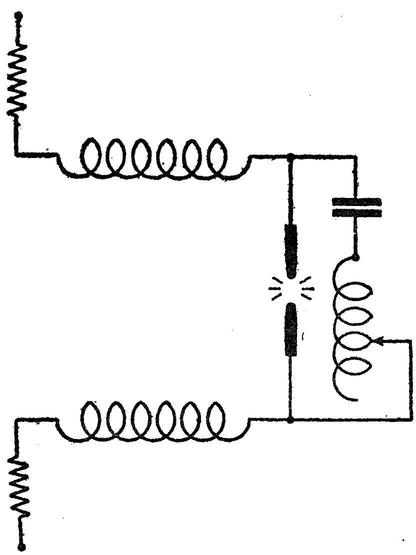
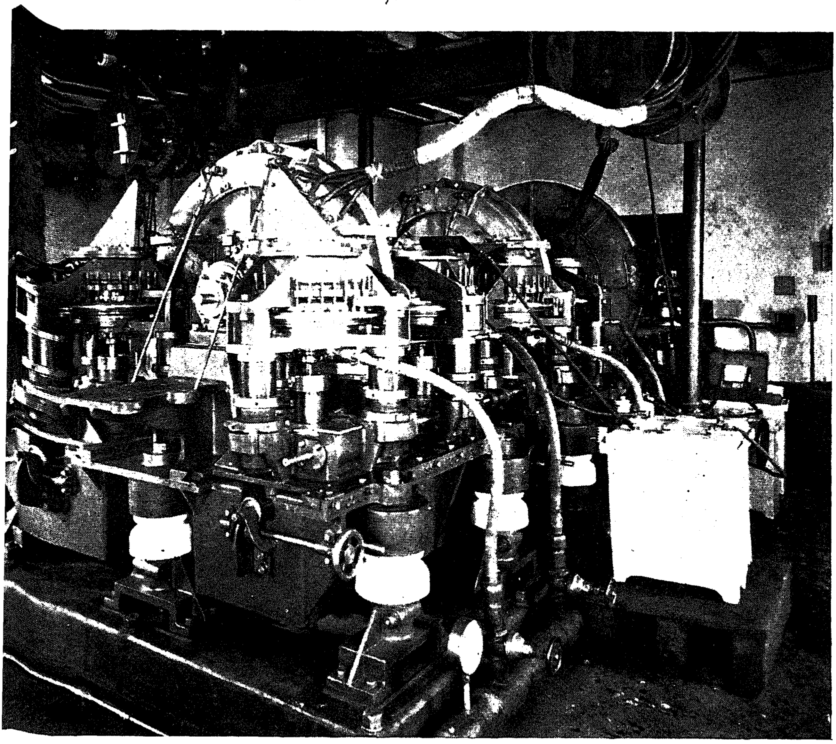


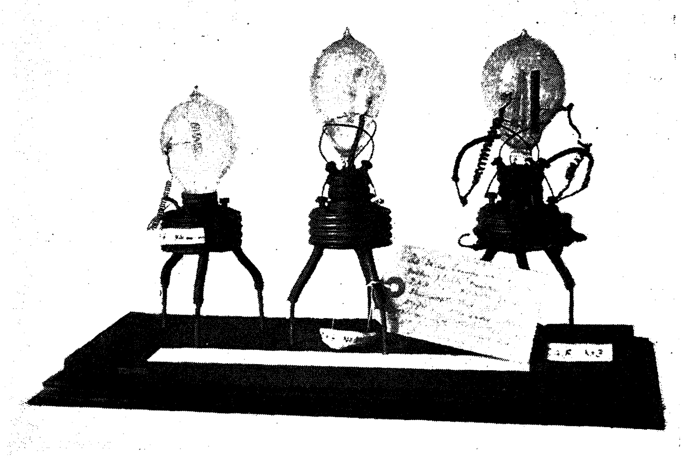
FIG. 12.—The Oscillation-producing Electric Arc applied as a generator of Electric Waves in Wireless Telegraphy.

PLATE 7.



[*By permission of Marconi's Wireless Telegraph Co., Ltd.*

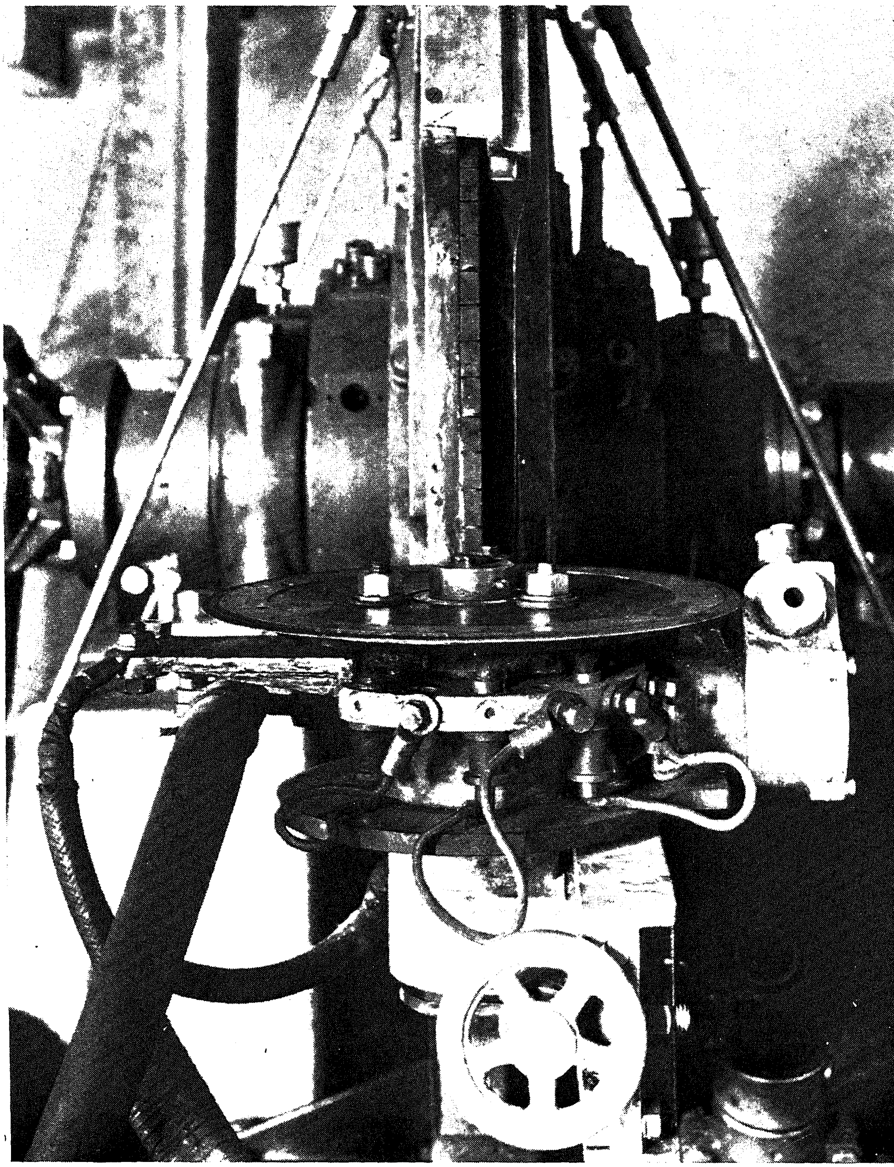
coni Timed Spark Continuous Wave Generator in Carnarvon Wireless Station.



The original Fleming Oscillation Valves first used in 1904 by the Author for the Rectification of High-frequency Currents as used in Wireless Telegraphy.

[*To face page* 326.

PLATE 8.



[By permission of Marconi's Wireless Telegraph Co., Ltd.

The Trigger Disk of Marconi's Timed Spark Continuous Wave Generator. The timed spark apparatus has two circuits tuned to the same frequency, which are coupled to the aerial wire by induction coils. Two sets of condensers are discharged alternately through these coils, and the function of the trigger disk is to make these discharges succeed each other in step, so as to create practically uniform continuous aerial oscillations.

[To face page 327.

then tuning cannot be so sharp as when employing prolonged wave trains.

It was soon seen that the best results would be secured by the employment of undamped waves, that is to say continuous or persistent waves, and not groups or trains of waves rapidly decreasing in amplitude.

Accordingly, attention began to be given to the production of such continuous waves (C.W.).

In 1900 the late Mr. W. Duddell described a method of producing persistent oscillations by an electric arc. If an arc is formed between solid carbon rods with a direct electric current, and if these carbons are connected by a circuit consisting of a condenser and an inductive resistance or coil of wire, electric oscillations will be set up in this condenser circuit (see Figs. 11 and 12). The steady electric current flowing through the arc turns aside to fill up or charge the condenser and then the next instant the condenser discharges itself back through the arc. Electricity, therefore, ebbs and flows in the condenser and produces high frequency oscillations. As long as the electric arc is formed in air it is difficult to obtain oscillations of much greater frequency than about 20,000 with any great energy in them. In 1903, V. Poulsen, a Danish engineer, made the important discovery that we can obtain undamped oscillations of very high frequency, even a million a second, and of very great energy, by enclosing the arc in a chamber filled with hydrogen gas or the vapour of some hydrocarbon liquid like alcohol, and at the same time placing the arc between the poles of a powerful electromagnet (see Fig. 13).

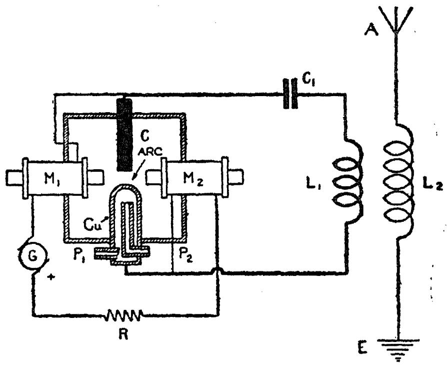


FIG. 13.—The Poulsen Electric Arc applied as a Wave Generator in Wireless Telegraphy. The arc is formed in a box full of coal gas or alcohol vapour between a carbon rod C and copper rod *Cu* and placed in a powerful magnetic field created by electromagnets M_1 M_2.

The full explanation of the mode of operation of this Poulsen arc, as it is called, is rather too technical for these pages, but will be found described in the author's books, *The Principles of Electric Wave Tele-*

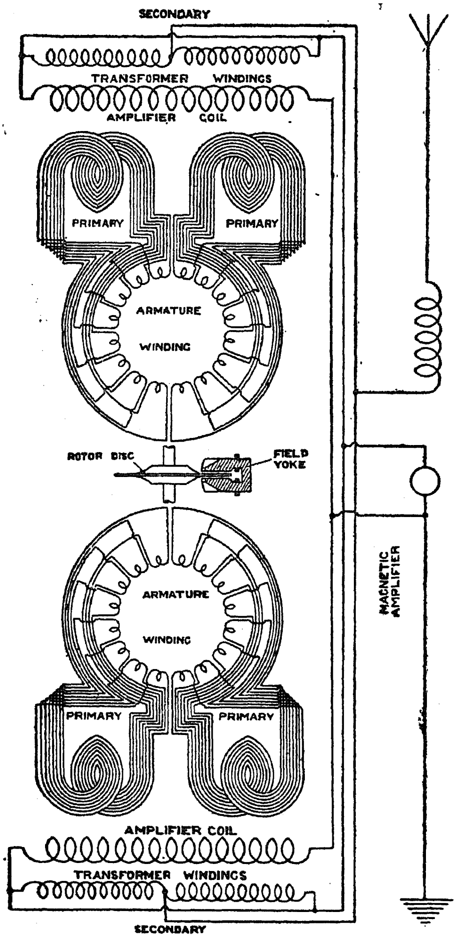


Fig. 14.—Scheme of Connections of an Alexanderson High Frequency Alternator for generating Continuous Electric Waves. This alternator is an Inductor alternator (see Fig. 11, Chapter II). Each group of armature coils is connected to a wire which forms part of a stranded primary coil of a step-up transformer. The high potential high frequency currents of 20,000 frequency or more are sent directly into an aerial wire and this then radiates continuous or undamped electric waves. For a general view of the machine see Plate 6, in which the static transformers are shown on the top of the alternator.

graphy or *An Elementary Manual of Radiotelegraphy* (Longmans & Co., London). This discovery made possible the production of powerful continuous electric or undamped electric waves, and at the present time many large stations and ship installations are operated by it. A view of a modern powerful Poulsen arc generator for creating continuous electric waves is shown in Plate 6 (page 323, upper diagram).

Another method has also been developed for creating undamped oscillations by means of high frequency alternators. We have described in Chapter II. the general construction of dynamos for generating alternating currents of electricity which flow to and fro in a circuit, say, 50 or 100 times a second.

The same principles can, however, with constructive modifications, be employed to build alternators giving currents of 50,000 to 100,000 periods per second.

In the United States Mr. E. F. W. Alexanderson has designed such high frequency alternators of 200 kilowatt power and upwards (see Fig. 14).

In France, alternators of similar power have been designed by M. Marius Latour, and in Germany R. Goldschmidt has constructed high frequency alternators on a rather different principle, which multiply up or increase frequency.

These high frequency alternators provide a simple and very mechanical solution of the problem of creating undamped powerful electric waves of great wavelength, say, 10,000 to 50,000 feet in wavelength for large power radio stations.

In a new, large and very powerful radio station for long distance working, to be established by the Radio Corporation of America, on the north shore of Long Island in the U.S.A., twelve steel towers 400 feet high will be erected to support the aerial wires, and alternating current will be supplied to these aerials by ten Alexanderson alternators of 200 kilowatts each (Plate 6, page 323). High frequency alternators are also used in the large French radio station at Lyons. In such a high frequency alternator station there is no need for condensers or spark gap; the alternators have one terminal connected to the aerial wire and the other to the earth plates, and they create in these aerials high frequency electric currents which run up and down the wires and radiate from them powerful electromagnetic waves.

A third method of generating powerful, high frequency, undamped oscillations was invented by Senatore Marconi and called by him the *timed spark* method (see Plates 7 and 8, pages 326 and 327).

In this system two sets of condensers consisting of glass plates coated on both sides with metallic sheets and forming, therefore, vast Leyden jars, are kept charged with electricity by continuous current dynamos of high voltage, say, 10,000 volts.

These condensers are discharged alternately through one coil of an oscillation transformer called a transmitting jigger, the secondary coil of which has its terminals connected respectively to the aerial wires and to the earth plate.

This discharge is effected by a multiple studded disk discharger, which causes a series of condenser discharges to take place at regular intervals so that the train of oscillations produced in the jigger by one discharge is followed by another train timed by a trigger disk in such manner that the oscillations of the second set begin just when those of the first end, and exactly in step with them. The result is to produce a series of slightly damped oscillations which run together into a series practically equivalent to undamped or persistent oscillations. This

method is in use at present (1920) at the large Marconi station at Carnarvon, Wales, employed for transatlantic wireless telegraphy.

There is a fourth method for creating continuous waves of steadily increasing importance, called the valve method, which has developed out of an invention made by the author in 1904 of the *oscillation valve* for the detection of electric waves.

We have already explained that in the spark system of wireless tele-

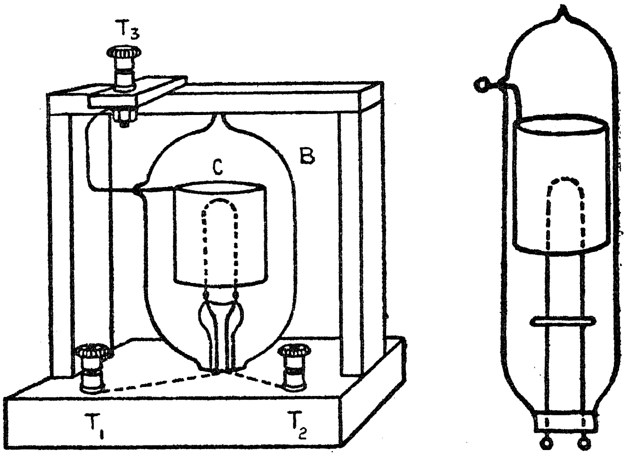
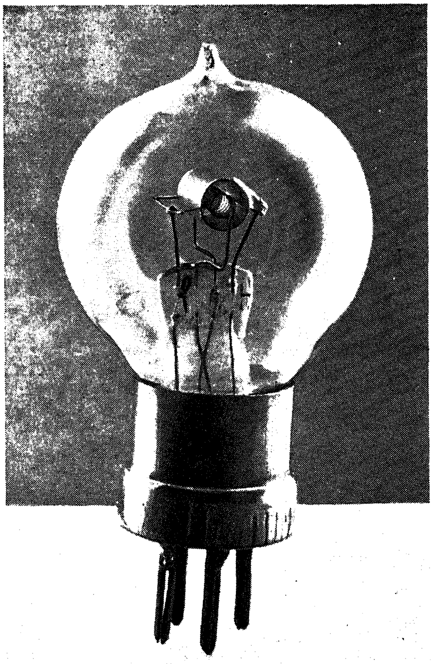
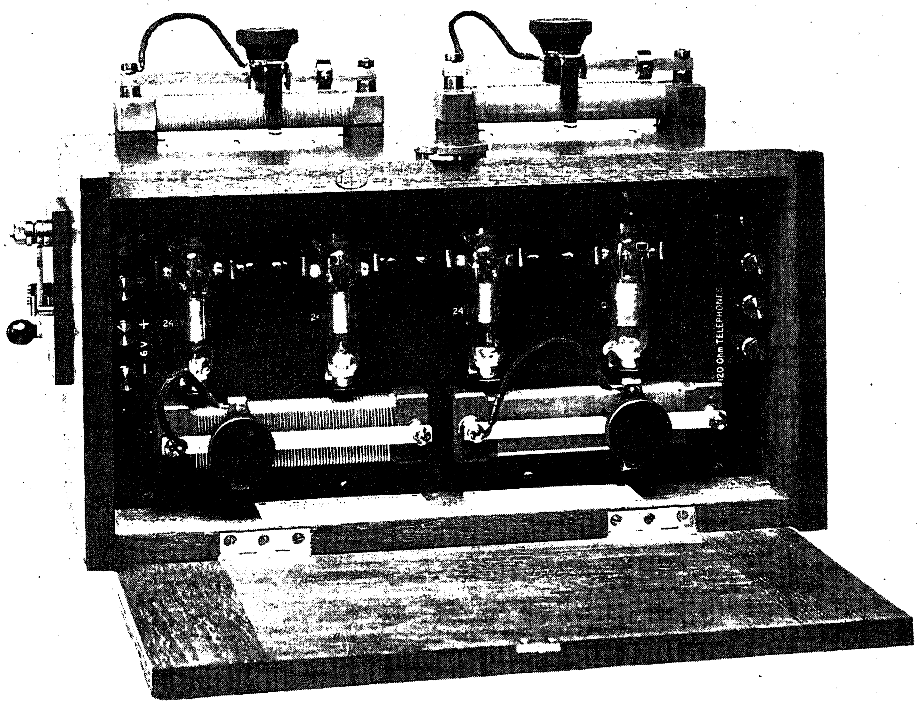


FIG. 15.—Fleming Thermionic or Oscillation Valves. They consist of little electric incandescent lamps having a tungsten filament. Surrounding this filament is a metal cylinder carried on a wire sealed through the glass. When the filament is incandescent the space between the filament and cylinder will conduct negative electricity only from the filament to the cylinder. Hence it *rectifies* a high frequency alternating electric current; that is, allows current to pass only in one direction.

graphy the electric vibrations in the aerial wire are created by the discharge of a condenser across a spark gap. These oscillations, therefore, come in groups or trains corresponding to each spark, and as there may be from 50 to 500 sparks per second there are 50 to 500 trains of oscillations and, therefore, of radiated waves, each of which may contain 20—100 oscillations or waves. The interval of time between two successive movements of electricity or waves may be of the order of a millionth or half a millionth of a second. These vibrations are too quick to affect a Bell telephone or even the human ear. If we convert the oscillatory

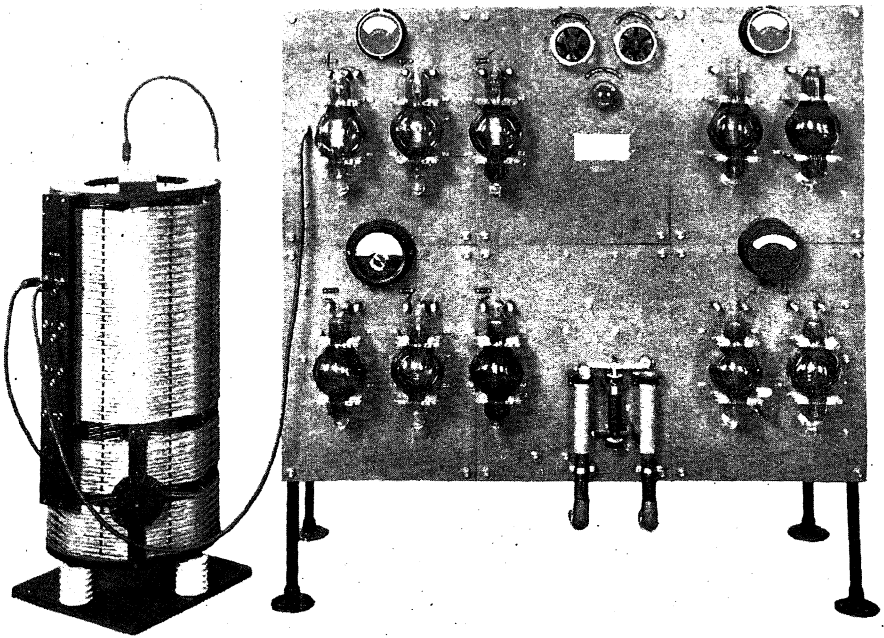


A Modern Three-electrode or Thermionic Valve of a type commonly called the "French" or R Valve.



[By permission of Marconi's Wireless Telegraph Co., Ltd.

A Valve Receiver as made by the Marconi Company, comprising four three-electrode valves in series or cascade. (See page 336.)



A Six-kilowatt Thermionic Valve Transmitting Panel as made by Marconi's Wireless Telegraph Company. The four valves on the right-hand side of the panel are Fleming rectifying valves, and their function is to rectify or change a high-pressure alternating current into a direct current for supply to the plate circuits of the six three-electrode valves on the left side of the panel. The result is to produce high-pressure high-frequency electric oscillations in the coil of wire (on the left-hand side), which are used for the production of continuous electric waves.

[*Reproduced from the "Radio Review.*'

A large Three-electrode Generating Thermionic Valve. The bulb is about 1 foot in diameter. (See page 336.)

movements of electricity in each train into a single gush or flow of electricity in one direction, then we change the trains into short flows of electricity all in one direction, these gushes coming at the spark frequency viz., 50—100 per second. For such intermittent currents the telephone is very sensitive. Accordingly, it appeared to the author in 1904 that if we could find some kind of conductor which would act like a valve for high frequency currents and let currents in one direction pass, but stop currents in the opposite directions, we should be able to *rectify* the trains of high frequency oscillations set up in a receiving aerial and detect them by a telephone or any equivalent direct-current instrument. Meditating on this problem the author found the solution by making use of an incandescent electric lamp with a plate of metal sealed into the bulb.

The author had carefully studied in 1883 and 1896, as already mentioned in Chapter III., the so-called "Edison Effect" in glow lamps discovered by Edison in 1883, and by 1904, as a consequence of the researches of Sir J. J. Thomson, it was well known that an incandescent filament of carbon in a high vacuum was giving off torrents of electrons or particles of negative electricity. Also, it had been found by the author that the space in a high vacuum between an incandescent cathode and a cold anode could conduct negative electricity from the hot to the cold electrode, but not in the reverse direction. It was not at all obvious, however, that a carbon filament incandescent lamp with a plate sealed into the bulb could be used to rectify high-frequency alternating currents; that is, to convert them into continuous or direct currents. Mr. Edison had made no such use of his "Edison effect" lamps, nor had it occurred to any one, until the author pointed it out, that such a lamp, having a metal cylinder surrounding the filament and carried on a wire sealed through the bulb (see Fig. 15), could be used to rectify high frequency currents and, therefore, as a detector of electric waves in wireless telegraphy.

The author, however, constructed in 1904 some carbon filament incandescent lamps in which the filament was surrounded by a metal cylinder carried on a platinum wire sealed through the bulb (see Plate 7, page 326, lower diagram). These lamps had their filaments made incandescent by a six-cell storage battery, and they were connected, as

shown in Fig. 16, with the receiving circuit of a wireless telegraph apparatus. The electric waves striking the aerial wire set up in it rapid electric oscillations or electric currents running up and down the wire. These created, by induction, other electric currents in the condenser circuit connected to the aerial wire. To one terminal of the condenser the metal cylinder of the lamp was joined, and the end of the carbon

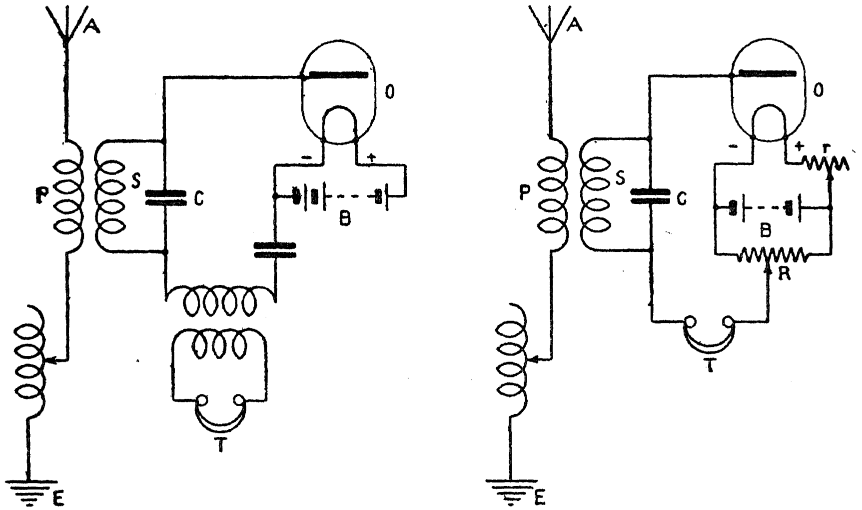


Fig. 16.—Diagrams illustrating the mode of use of a Fleming Thermionic Valve as a Detector in Wireless Telegraphy. A is the receiving aerial and E is the earth connection. P S is the receiving jigger or transformer and C is the condenser. T is a telephone. The valve plate and filament are connected through the telephone or telephone transformer with the terminals of the receiving condenser and the valve rectifies the trains or groups of electric oscillations into gushes of electricity in the same direction which flow through the telephone circuit and cause a sound.

filament in connection with the negative terminal of the battery of cells was connected through a galvanometer or a telephone with the second terminal of the receiving condenser.

Hence, as the electric oscillations took place in the condenser, electric currents would flow through the telephone and through the vacuous space, but, as already stated, negative electrons are being given out by the hot filament, and, therefore, negative electricity only can pass from the filament to the cylinder in the bulb, but not in the opposite direction. Hence such a bulb operates to stop all current flow in one direction, but

permits it in the opposite ; in other words, it acts like a valve for electricity. The author, therefore, called it an *oscillation valve*, and it has generally been named a *Fleming valve* or *thermionic valve*. The result is to convert the trains of rapid oscillations produced in the condenser circuit into gushes of electricity all in the same direction through the telephone. These gushes come at intervals corresponding to the spark frequency, viz., 50—500 per second, and, therefore, produce in the telephone a uniform sound. This is cut up into short or long periods corresponding to the *dot* and *dash* of the Morse Code, when the signalling key in the transmitter is manipulated properly.

It was at once found that this thermionic valve gave us a very simple, easily managed detector of electric waves in radiotelegraphy.

By that time the coherer had become antiquated, and had almost entirely gone out of use, but the magnetic detector of Marconi remains to this day a portable and useful appliance in radiotelegraphy.

This, perhaps, is the place to mention another class of rectifying crystal detectors in wireless telegraphy which had very extensive use at one time.

The first of these was discovered by General H. H. C. Dunwoody in 1906, subsequent to the author's invention of the oscillation valve.

It was found that carborundum, a carbide of silicon, the electrical preparation of which has been described in Chapter IV., possessed the curious property that a crystal of it could conduct electricity better in one direction along the axis than in the opposite. It was, therefore, evident that it could be used to separate out the two constituents of an alternating current or rectify a train of electric oscillations into a gush or flow of electricity all in one direction. The crystal of carborundum could, therefore, be used in the same manner as the oscillation valve as a detector in wireless telegraphy.

Subsequently it was found that there were other crystals, such as anatase and hessite, which acted in the same manner, and, moreover, that there were several pairs of minerals which, when put in contact, exhibited a better electric conductivity in one direction than the opposite. Thus plumbago (graphite) and galena (sulphide of lead) is such a pair, and a better pair is zincite (oxide of zinc) and chalcopyrite (sulphide of copper and iron), discovered by G. W. Pickard.

Professor G. W. Pierce found that molybdenite (sulphide of molybdenum) has a unilateral conductivity, like carborundum.

These crystal detectors, from their low cost and simplicity of working, soon became the favourite detector of amateur wireless telegraphists. They were put in the background by subsequent improvements in the oscillation valve or thermionic valve, which have given us the so-called three-electrode valve, or thermionic tube or triode.

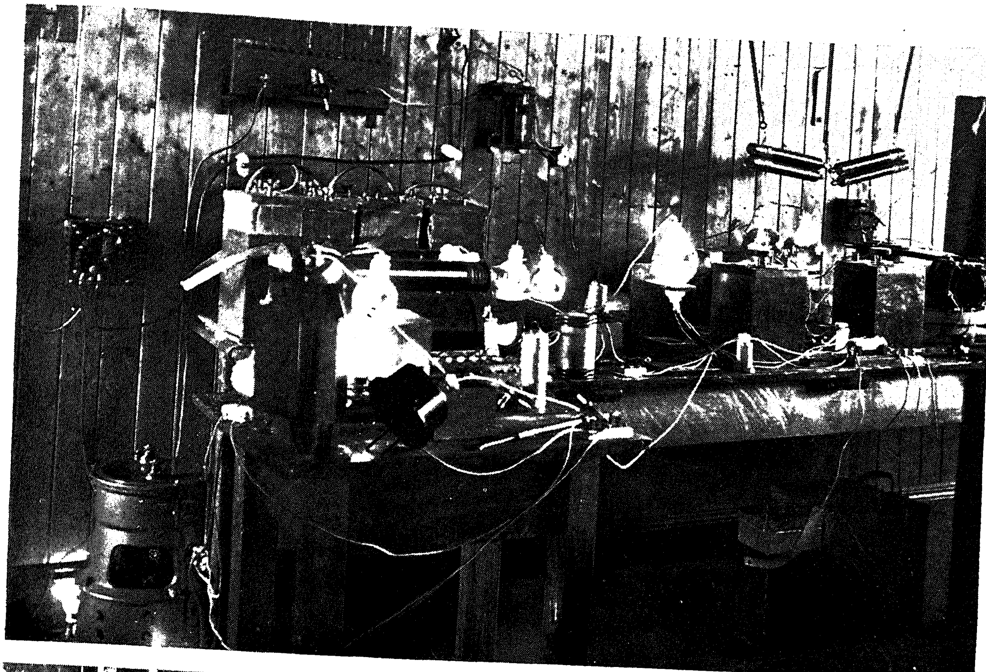
This improvement, due to Dr. Lee de Forest, consisted in introducing in one of the author's oscillation valves a grid or zig-zag of metal wire between the incandescent filament and the metal cylinder. As made generally at present the grid consists of a spiral of wire which surrounds, but does not touch, a straight filament of tungsten. Around the spiral is an enclosing cylinder of metal (see Plate 9, page 330, upper diagram). The author constructed one of the first three-electrode valves with a spiral wire grid in 1914 or before, and this type has now been standardised as a permanent type of receiving valve. This spiral or network cylinder is technically termed the *grid*, and the outer metal cylinder is called the *plate*. The incandescent filament is called the *hot cathode*. The grid and the plate are attached to platinum wires which are sealed through the wall of the glass bulb.

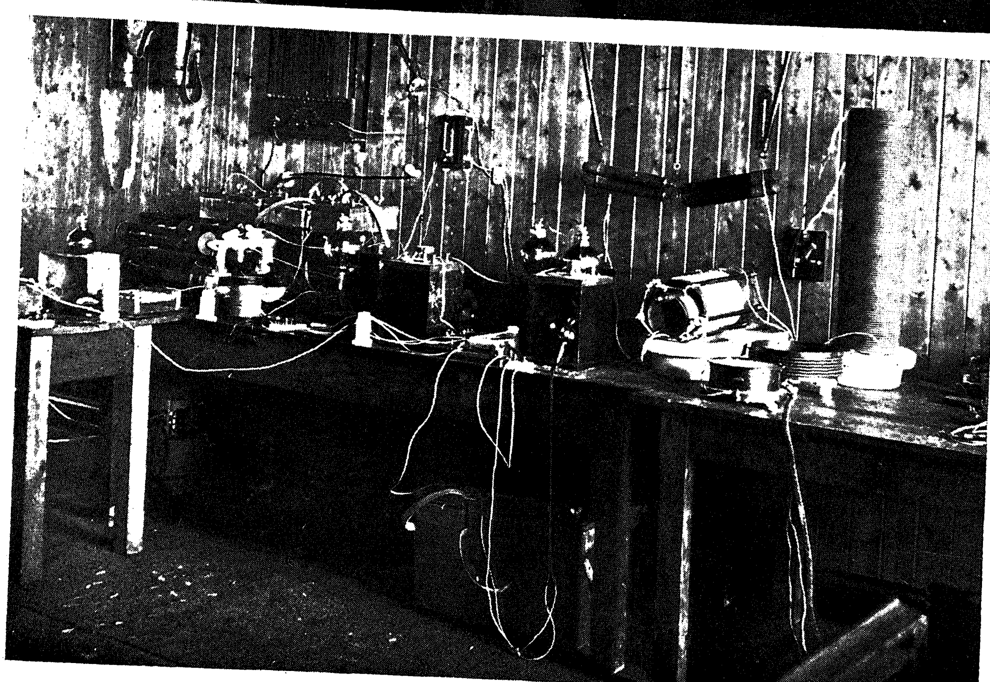
It is essential, as pointed out by the author in his fundamental Patent Specification,* that the vacuum in the bulb should be extremely high, or else disturbing effects are introduced by the ionisation of the residual air due to the electrons thrown off from the filament. Valves with a high vacuum in the bulb are called *hard* valves.

The three-electrode valve is used in the following manner :—If we make the filament incandescent by a battery and connect the negative terminal of another battery (called the plate battery) to the filament, and its positive pole to the plate, this last battery maintains the plate at a positive potential, and this attracts large numbers of electrons escaping from the filament. These electrons are liberated from the filament literally by millions per second, and to get to the plate they have to pass through the holes in the grid. The stream of electrons moving to the

* British Patent Specification, No. 24,850 of November 16th, 1904—J. A. Fleming. Also U.S.A. Patent No. 803,684 of April 19th, 1905. The use of tungsten for the filament of valves was first suggested by the author in a British Patent Specification, No. 13,518 of 1908.

PLATE II.





[By permission of Marconi's Wireless Telegraph Co., Ltd.

Views of the Interior of the Wireless Telephone Station at Ballybunion, Ireland, from whence wireless telephone speech was transmitted across the Atlantic Ocean in 1919 by the Marconi Company's engineers using thermionic valve transmitters and receivers.

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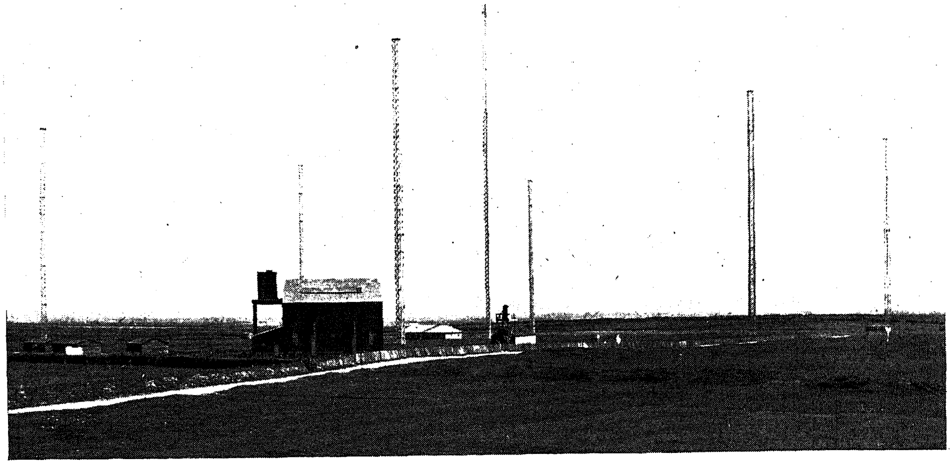
PLATE 12.



[*By permission of Marconi's Wireless Telegraph Co., Ltd.*

The upper view shows the Masts and Aerial Wires of the Ballybunion Station, Ireland, and the lower view the Masts and Aerial of the Carnarvon Wireless Station in North Wales.

[*To face page* 335

plate constitutes a current of negative electricity, called the plate current, passing from the filament to the plate through the bulb.

If now we give a small charge of negative electricity to the grid, or put on it a few electrons, these repel some of the electrons forming the

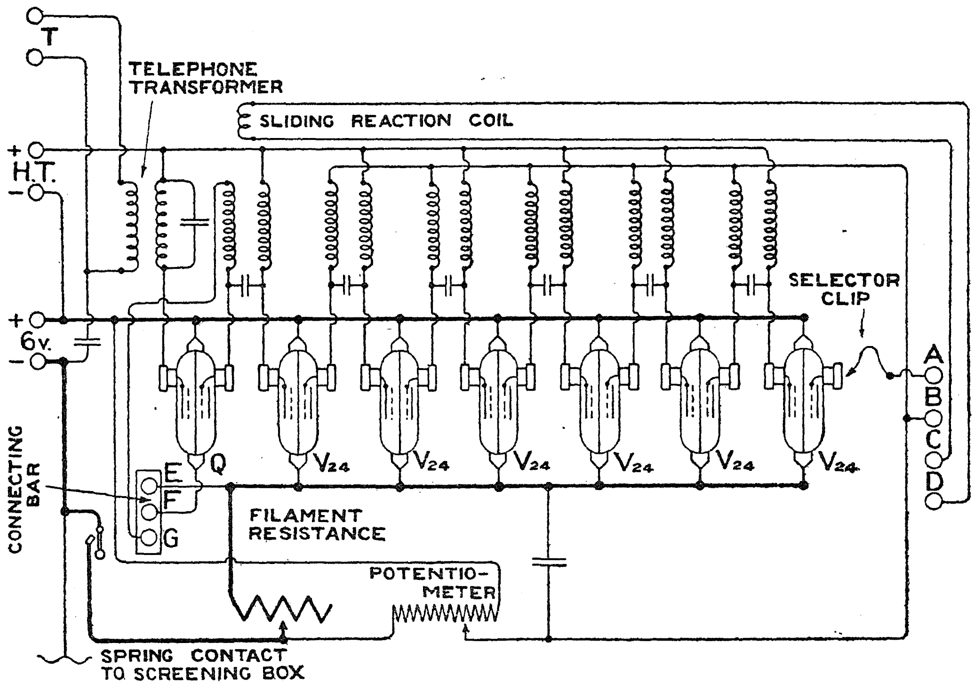


FIG. 17.—A Thermionic Valve Amplifying Receiver for Wireless Telegraphy. Comprising a series of six three-electrode valves arranged in cascade as magnifiers or amplifiers and one detecting valve at the end to rectify the oscillations. The general appearance of the four-valve instrument is shown in Plate 9, page 330, bottom diagram. It is this arrangement of thermionic valves in cascade which enables all the modern wonders of wireless telegraphy and telephony to be effected. The above form is made by Marconi's Wireless Telegraph Company.

plate current and prevent them getting to the plate. Hence, the plate current is reduced. If, however, we make the grid positive in potential, then the electrons are given a pull and the plate current is increased. So nimble are these little electrons that, however rapidly we change the electrification of the grid, the plate current is correspondingly altered, even at the rate of a million times per second.

Suppose, then, that we connect the grid and the filament of a three-

electrode valve to the terminals of the receiving condenser of a wireless receiver. The electrification of the grid will be alternately positive and negative. This causes a fluctuation in the plate current. If we pass this fluctuating current through the primary coil of a step-up transformer it will induce an electromotive force in the secondary circuit which will be a magnified representation of that applied to the grid. Hence, the thermionic tube and induction coil become an *amplifier* of potential changes or oscillations.

The valuable quality of this amplifier is that we can use one amplifier to act on the grid of a second tube and that, again, on a third, and so by using a number of thermionic valves *in cascade* we can make a detector of electric oscillations of enormous sensibility (see Fig. 17 and Plate 9, page 330, lower diagram).

All the great feats of long distance wireless telegraphy of late years, receiving messages for instance half way round the earth, have been only achieved by the use of suitably arranged thermionic valves worked in cascade. We may, indeed, call it the master weapon of the radio-engineer.

But this three electrode valve, and also the two electrode, or Fleming, valve, possesses the important property of being able to generate oscillations as well as detect them.

If, for instance, we pass the plate current through the primary circuit of an induction coil, and connect the terminals of the secondary coil respectively to the grid and the filament in a certain way, then any variation of grid potential will create a variation of plate current and this, again, by the aid of the induction coil may be made to create potential variations in the grid which maintain and exalt the variations of plate current. So used the thermionic valve becomes a self-acting producer of persistent or undamped electric oscillations, and a most valuable addition to the three other methods already described, viz., by the high frequency alternator, the Poulsen electric arc, and the Marconi timed-spark. It is possible to work a number of such thermionic generators in parallel so as to add together their separate currents.

In this case the high electromotive forces required to drive the plate currents are obtained by raising the potential of a low frequency alternating current by a transformer and then rectifying this current or con-

verting it into a direct current by means of a set of two-electrode or Fleming valves. Thermionic valves used as generators are now called transmission or power valves, and the bulbs of glass or silica in some cases are made as large as footballs or nearly a foot in diameter.

Thermionic generating apparatus on this plan is now made up to several kilowatts in power output, and our illustration in Plate 10, page 331, represents a 6-kilowatt set made by Marconi's Wireless Telegraph Company, whose engineers have devised many important forms of valve generators.

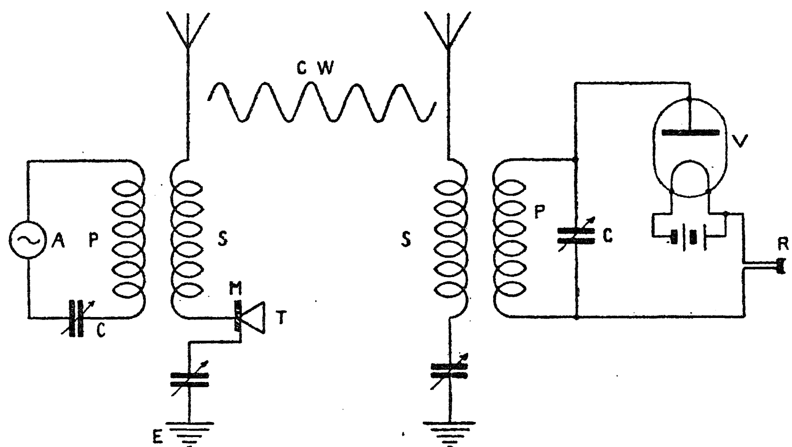


Fig. 18.—A Diagram illustrating the Nature of the Apparatus for Conducting Wireless Telephony. On the left-hand side is the transmitter by which continuous electric waves are thrown off from the aerial. These are altered in amplitude or height by speaking to the microphone T. At the receiving station (on the right) the aerial picks up these waves, and they are rectified by a thermionic valve V and heard as speech sounds in the telephone receiver R.

In 1910, the Government appointed a committee on Imperial Wireless Telegraphy, and this committee recommended the use of thermionic valves for generators of persistent waves for high power stations to be erected by the State.

Expert opinion, however, differs very much as to the relative advantages of the H.F. alternator, the arc, the timed-spark and the thermionic valve as generators for such high power stations.

The invention of the thermionic generator has, nevertheless, completely solved the problem of wireless telephony and made it possible over immense distances.

The general principles of this art must next be briefly explained.

Suppose that at a transmitting station we have an aerial wire in which persistent or undamped oscillations are set up by a high frequency alternator A, and at a receiving station we have a receiving aerial coupled to a tuned condenser circuit and the terminals of this condenser connected by an oscillation valve in series with a telephone as in Fig. 18. Let a speaking carbon microphone, as described in Chapter I., be inserted in series with the transmitting aerial. Then, if speech is made to it, the resistance of the carbon granules will be varied by the voice and hence the oscillatory current in the aerial wire, and, therefore, the amplitude or height of the electric waves emitted by the aerial will be varied in a manner which imitates the *wave form* (see Chapter I.) of the speech sounds made to the microphone. It follows that the rectified received current flowing through the telephone receiver will be altered in the same manner, and therefore the Bell telephone will give out sounds or articulate speech exactly imitating that made to the microphone transmitter.

We thus are able to achieve wireless or radiotelephony (see Fig. 18).

In the actual apparatus the persistent oscillations in the sending aerial are created by a three-electrode thermionic valve, and the speaking microphone has a cell or two of a primary battery in series with it and also the primary circuit of an induction coil. The secondary circuit of this coil is connected to the grid of one of the transmitting valves and so varies the oscillatory current produced.

By this means articulate speech has been transmitted across the Atlantic.

Important experiments were conducted in March, 1919, by the Marconi Company's engineers and experts between Ballybunion, Co. Kerry, Ireland, and Louisberg, in Nova Scotia. Masts 600 feet high were set up at both stations to support a number of aerial wires. Thermionic generating valves were used, and a small alternator of about 2·5 kilowatts output supplied the necessary power.

The receiving apparatus consisted of a number of thermionic valves (six) in cascade. The speech transmission was perfectly good over the 2,000 miles distance, but for regular working rather more power would be required (see Plates 11 and 12, pages 334 and 335).

The tests showed that it is quite within the bounds of possibility to speak direct from London to New York by radiotelephony if a sufficient demand for the communication should be made. Not only so, but by means of the thermionic repeater described below it is possible to transfer telephonic speech from ordinary wire telephone circuits to a wireless aerial and so fling it through space, or conversely to pick it up from a radio circuit and repeat it to a wire circuit.

This thermionic valve apparatus, both generator and transmitter, can be made sufficiently compact to be placed on an aeroplane. The aerial wire is generally about 250 feet long and trails in the air behind the aeroplane as it flies. The electric current required for the valves is supplied by a small dynamo fixed to the outside of the " plane " and driven by a screw rotated by the air rushing past (see Plate 13, page 344).

The great difficulty has been to enable the observer to hear the telephonic speech through the terrific air and engine noises. He wears a kind of helmet with the telephone receivers fixed over the ears in india-rubber cups. Types of microphone transmitter were devised during the war which enabled speech to be transmitted by the observer, but which did not take up readily the engine and propeller noises.

With such equipment speech can be transmitted to or from aeroplanes in flight to a distance of fifty miles or more. Strange to say, by means of valve amplifiers it has been possible to relay or connect ordinary telephone lines to radiotelephone receivers and transmitters. Experiments on this matter have long been in progress at the Air Ministry under the direction of Colonel L. F. Blandy.

The perfection of this interlinking would render it possible to speak say to an aeroplane in flight for Paris from the transmitter of any subscriber on the London exchanges. There are, in fact, vast possibilities open in connection with radiotelephony.

The thermionic valve in its three-electrode form has been found to be a perfect solution of the great problem of relaying or repeating telephonic speech. The nature of a telegraph relay has been explained in the introductory chapter. It is a device for repeating more strongly by means of a local battery on to a second telegraph line or instrument signals received by very feeble currents on a first line. In the same way a telephone

relay or repeater is an instrument actuated by telephonic electric currents too feeble to give good speech in a Bell receiver, but which by means of

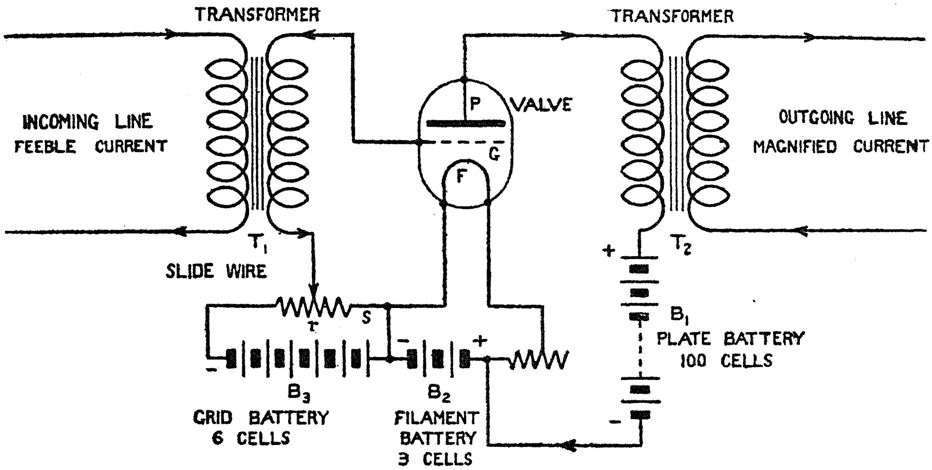


FIG. 19.—A Thermionic Amplifier used as a Telephone Relay or Repeater.

energy drawn from a local battery amplifies these speech currents for re-transmission along a second line for better hearing in a receiver. Many

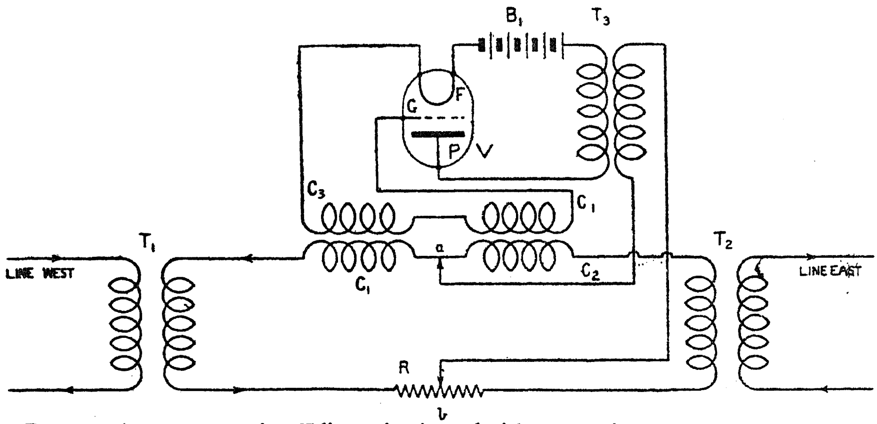


FIG. 20.—Arrangement of an Edison Circuit used with a Thermionic Telephone Repeater.

forms of microphone telephone relay have been devised, but hardly any one could be called a complete success. We have explained above that in a three-electrode valve very feeble variations of the grid potential

may be made to make large corresponding variations of the plate current.

Imagine, then, an induction coil having its primary circuit connected to the receiving end of a telephone line. Let its secondary circuit be connected to the grid and filament of a three-electrode valve. In the plate circuit let there be a battery and also the primary coil of another transformer, and let the secondary coil of this last be connected either to a second telephone line or to a Bell receiver. Then in accordance with what has been explained this arrangement will magnify or amplify the feeble telephonic currents received from the first line and repeat them in augmented strength, but perfect accuracy, to the second line (see Figs. 19 and 20). This arrangement is called a thermionic repeater, and it is being used on long telephone lines, such as the New York—San Francisco line in U.S.A., and is being carefully tested by our British Post Office Telephone Department.

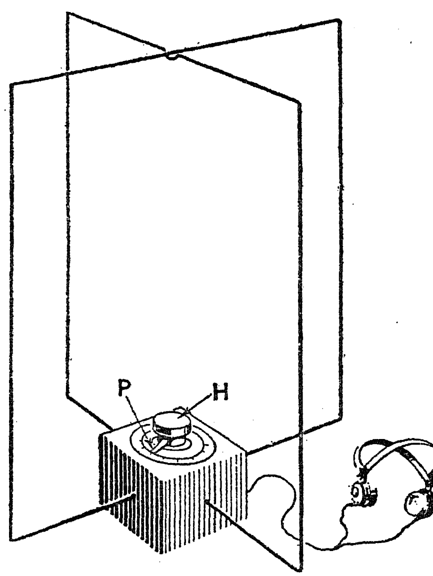


Fig. 21.—A Quadrilateral Receiving Frame Aerial for Directional Wireless Telegraphy. By this we are enabled to determine the direction of the source of the waves.

If our trunk line system of conductors had to be relaid much copper could now be saved by the use of this thermionic repeater.

We must next mention a branch of radiotelegraphy to which much attention was given during the War, viz., directional wireless telegraphy. In the quite early days of radiotelegraphy it was noticed that an aerial wire which is not quite vertical, but slants, sends out its waves a little unsymmetrically.

In 1906, Senatore Marconi, in a Paper to the Royal Society, communicated by the author, made known his discovery that an aerial wire which is partly vertical and then bent over horizontally sends out its

radiation most strongly in a direction opposite to that towards which its free end points, and receives best from that direction. Later on it was found that closed circuit aerials in the form of a square or triangle radiate best in the plane of the area, and receive best in that plane. Hence, if we put a few turns of wire round a square frame, called a frame aerial, and connect the ends to a suitable condenser and to an amplifying valve detector, and hold up the frame with its plane vertical, it will receive well signals sent out from a station lying in the direction of the plane of the frame, but none at all in directions at right angles (see Fig. 21).

Hence, if we wish to ascertain the point from which radio signals are

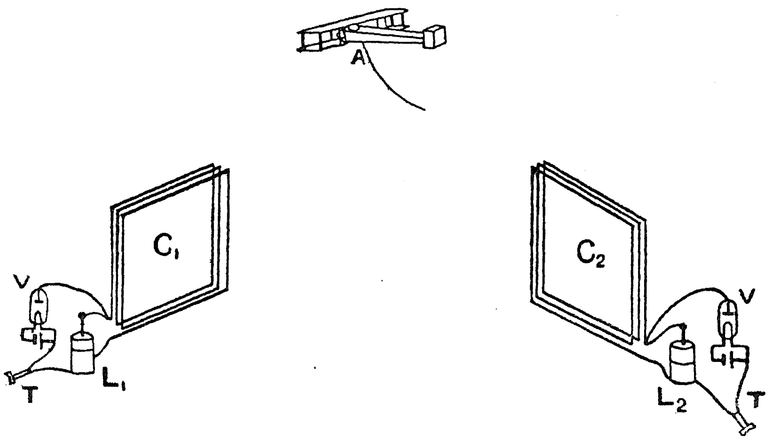


FIG. 22.—A Diagram showing the manner in which two receiving Wireless Stations equipped with Directional Frame Aerials can determine the Position of an Aeroplane which is sending out Wireless Signals by its trailing Aerial Wire A.

being sent out, we have to establish two receiving stations at a known distance apart at both of which there are frame aerials which can be rotated round a vertical axis. If these stations simultaneously fix the direction of the radiant point, then it is clear it must lie at the intersection of the lines indicated by the planes of the two frames produced. These lines can be laid down on a map and the exact position of their intersection found. Two such directive stations can thus pick up simultaneously radio-signals sent out by a ship in a fog or an aeroplane lost in the clouds, and can fix its position and communicate back with the ship or aeroplane and give it information as to its position at sea or in the air (see Fig. 22).

This directive telegraphy was of great use in fixing the position of Zeppelins, or enemy aircraft which happened to use wireless telegraphy, because this at once gave away their position in space to our observers. Very important improvements in this directional wireless were made by Captain H. T. Round during the War in improving somewhat rudimentary appliances into precision methods.

The outcome of nearly twenty years' labour and invention in this fascinating branch of applied science has been to cover the world with radiotelegraphic stations, first, for intercommunication with ships at sea, called coast stations, and, secondly, with large high-power radio-stations for long distance transmission and regular commercial working. In Great Britain Marconi's Wireless Telegraph Company have three large stations at Poldhu, in Cornwall, Clifden, in Ireland, and Carnarvon, near Snowdon, in Wales. In this last-named station the aerial is a multiple wire bent or directive aerial carried on ten steel masts, each 400 feet high. The waves sent out are undamped waves produced by the tuned-spark method. About 500 h.p. are conveyed to the station by overhead power lines from the North Wales Electric Power Company at Cwm Dyli, which draws its power from the lakes, such as Llyn Lydaw, situated high up on Snowdon (see Plate 12, page 335).

The Carnarvon station communicates with a station in the United States in New Jersey. The British receiving station, however, is not at Carnarvon, but at Towyn, on the Welsh coast, about sixty miles away. The object of this separation is to allow reception and transmission of messages to go on simultaneously (see Plate 14, page 344). In France there are, in addition to many coast stations, four high-power stations, one at the Eiffel Tower, Paris, in which the tower itself, 1,000 feet high, is used to support the aerial wires. This station is under the control of the Ministry of War. The second is at Basse Lande, near Nantes, the third at La Doua, near Lyons, and the fourth, which is one of the largest radio stations in the world, at Croix d'Hins, near Bordeaux. This last station was built by the Americans during the War for communication with the United States. It has eight towers, each 820 feet high, to support the aerial wires.

The Lyons station was built for communication with North Africa,

but it is capable of reaching as far as Indo-China, 5,000 miles away. In Germany there are power stations at Nauen, near Berlin, and at Hanover. This last was built for intercommunication with one at Tuckerton, New Jersey, in the United States and is worked with Goldschmidt high-frequency alternators (see Plates 15 and 16, page 345).

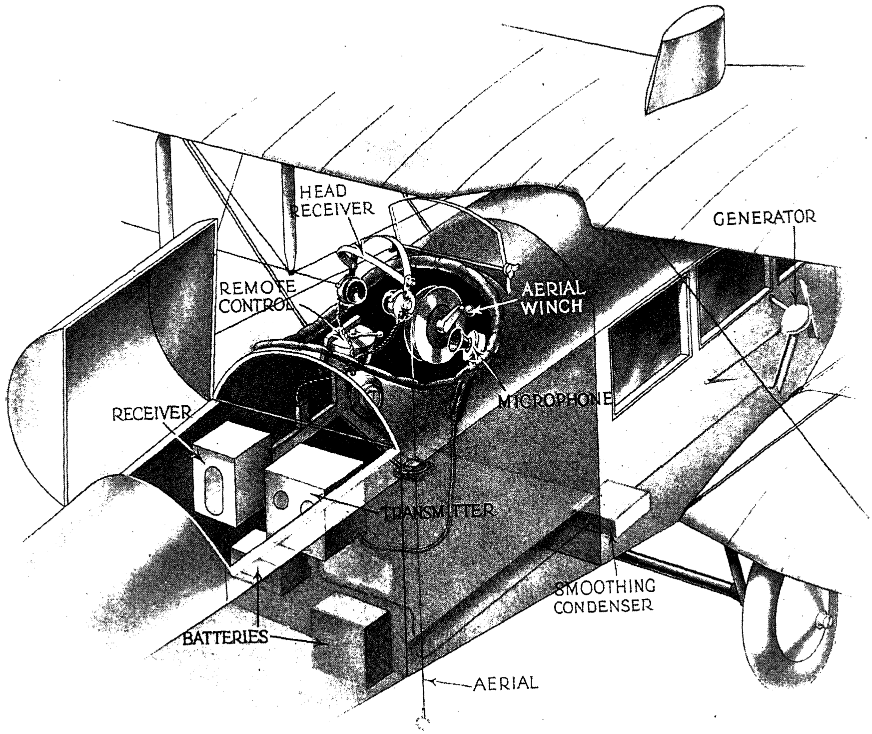
In October, 1900, the plans for the first small 25 h.p. long distance radio station in the world, viz., the Marconi station at Poldhu, in Cornwall, were drawn on the author's lecture table at University College, London. Twenty years later we find the world covered with gigantic power stations for transmitting half round the world electromagnetic waves of immense energy for telegraphic purposes, employing thousands of horse-power and exhibiting in every part the results of immense scientific thought and invention, the outcome of very costly experiments by numerous talented radio engineers and experts. Thirty years ago the æther round the earth was undisturbed except by the short wave disturbances which affect our senses as light and heat. Now it is everywhere traversed by long waves or billows which are the waves employed in wireless telegraphy.

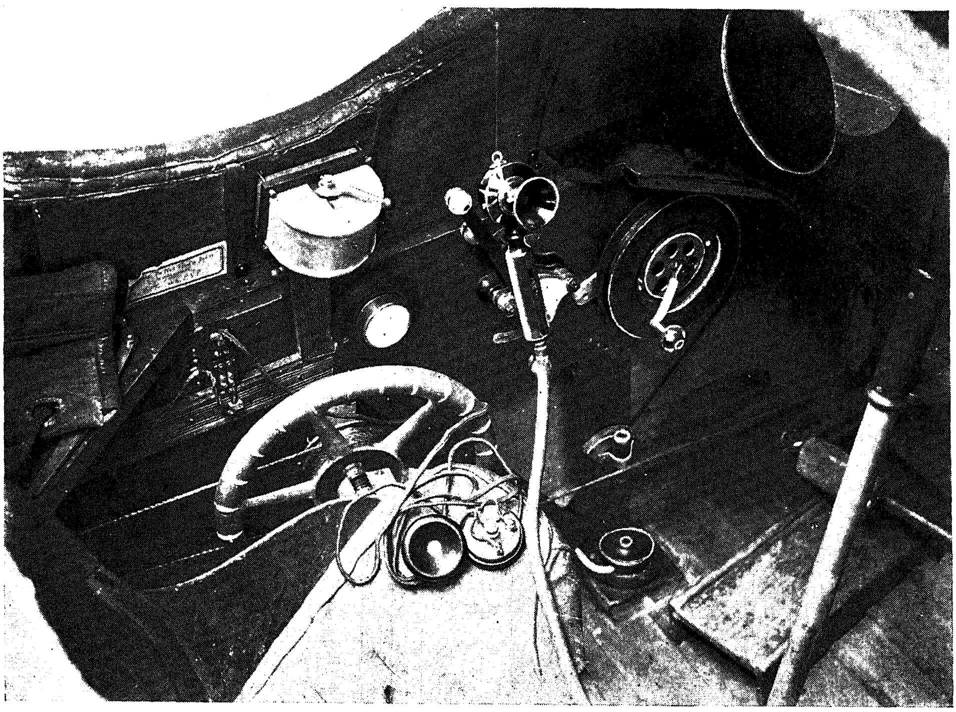
There is one interesting matter which should be mentioned in connection with long distance wireless telegraphy, which was discovered during the first attempts to bridge the Atlantic.

In one of his early voyages across the Atlantic in 1902, Senatore Marconi discovered that the signals from Poldhu could be detected at a greater distance during the night than the day. Sunlight seemed to act as if it were an obstruction to the propagation of the electric waves. This question has been very much discussed by physicists and mathematicians during the last few years. A ray of light bends round an opaque obstacle to a very small extent, and this effect is called diffraction. The question then arose whether the transmission of radio waves to a distance of 12,000 miles or half way round the earth is an effect of diffraction. This subject has engaged the attention of some of our most eminent physicists, and they are now generally agreed that normal diffraction alone will not account for the success of long distance radio-transmission.

It appears highly probable that the earth's atmosphere in the higher regions is in a state of ionisation, that is, there are atoms which have lost or gained electrons. These ions give to the rarefied upper air electric

PLATE 13.



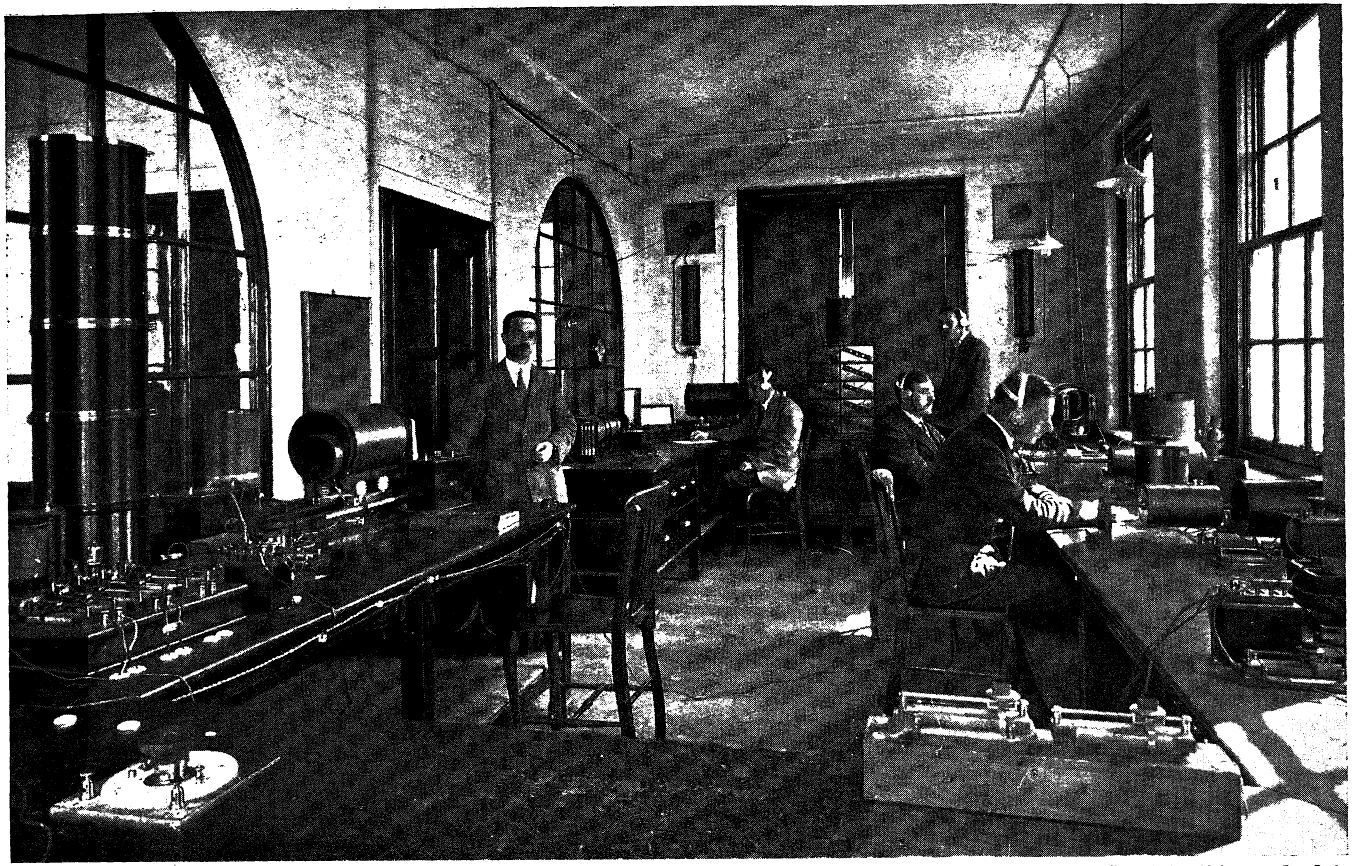


[*Reproduced from the "Radio Review."*

The arrangement of Wireless Telephone and Wireless Telegraph Apparatus in an Aeroplane. The aerial wire is kept rolled up on a drum, and is paid out by the pilot when he wishes to send or receive a message.

[*To face page* 344.

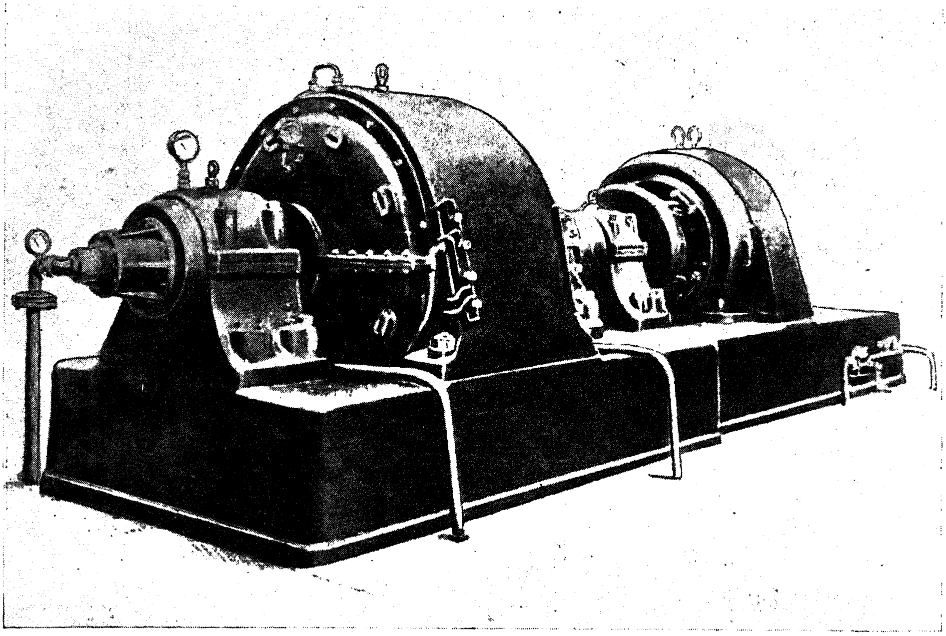
PLATE 14.



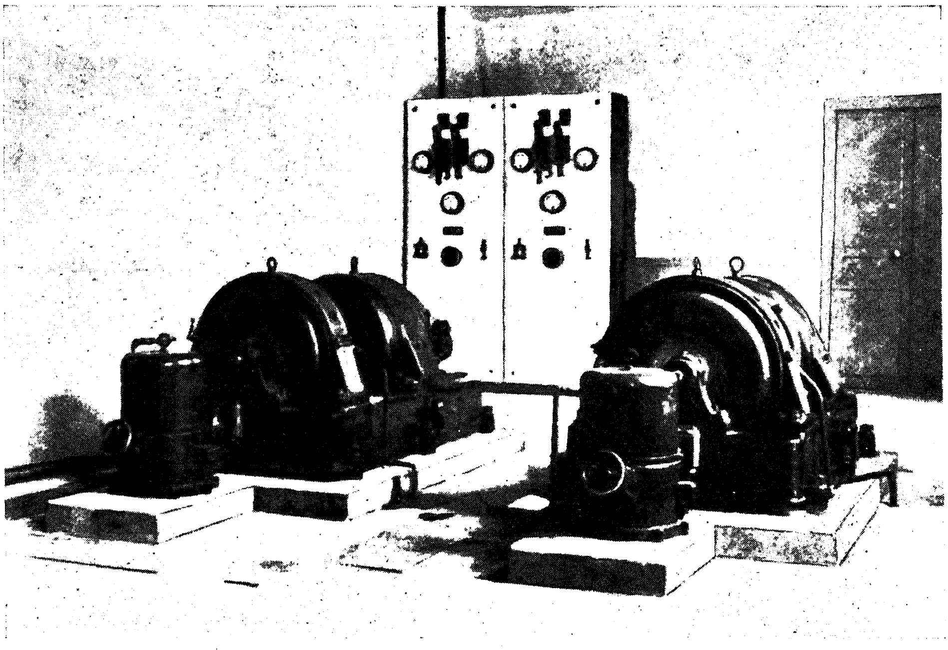
[By permission of Marconi's Wireless Telegraph Co., Ltd.

A View of the Interior of the Wireless Receiving Station of Marconi's Wireless Telegraph Company at Towyn, North Wales. At this station the signals coming from the New Jersey Station, U.S.A., are received. From Towyn the signals sent out from the Carnarvon transmitting station are controlled.

PLATE 15.

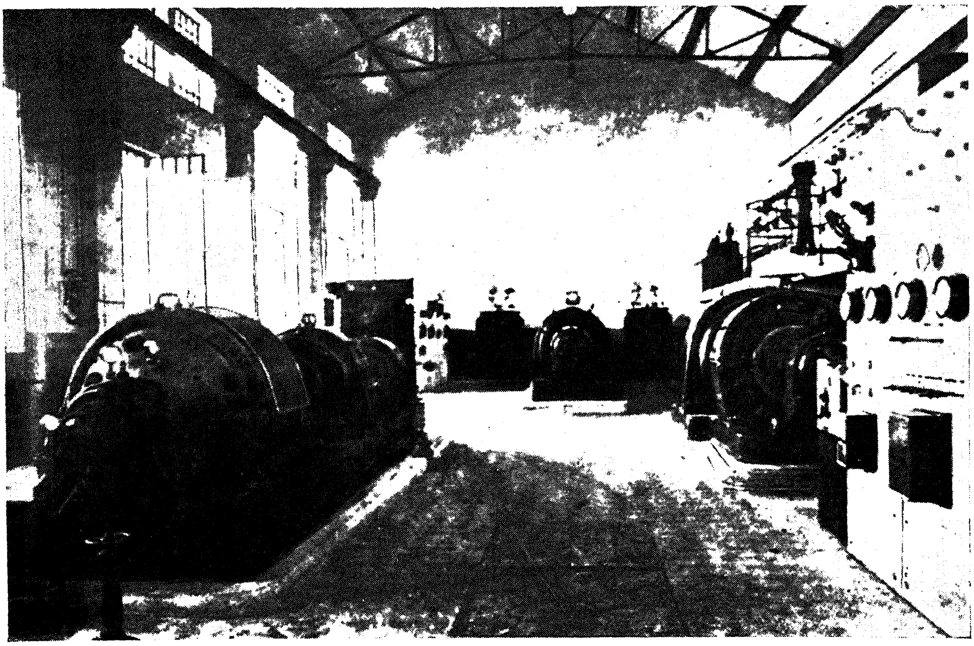


High-frequency Alternator installed in the Radiotelegraphic Station at Lyons, France, of 225 kilowatt output. The machine runs in a metal case in which a vacuum is made to reduce loss of power by air churning.

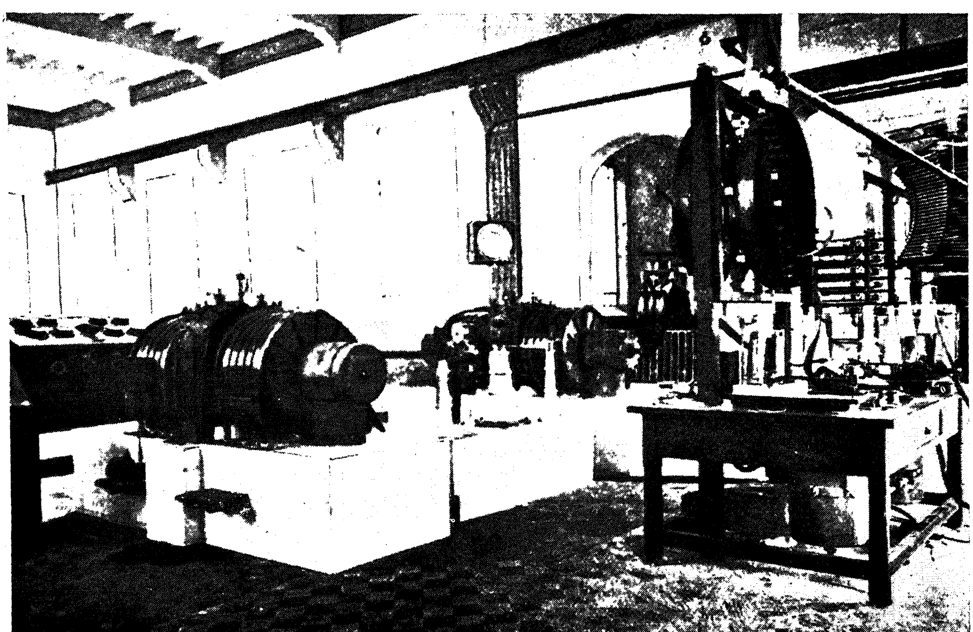


Two 50-kilowatt High-frequency Alternators installed in a Radiotelegraphic Station used in parallel with each other. This method of providing the high-frequency currents in radio stations has great advantages.

PLATE 16.



A View of part of the Interior of the large Wireless Telegraph Station at Lyons, France, showing the 200-kilowatt High-frequency Alternators. This station can communicate over a distance of 5,000 miles or more.



A View of the Interior of part of the large Radiotelegraphic Station at Lyons, France, showing the 400-kilowatt Arc Transmitters on the Poulsen-Elwell System.

[*To face page* 345.

conductivity. This ionisation is to some extent an effect of sunlight and, in part probably, of fine electrically-charged dust projected from the sun. The electromagnetic waves sent out by radio stations are, therefore, reflected by this ionised layer of air called the Heaviside layer, and the result is that the distant receiving stations are affected indirectly, just as places are illuminated by the light of the sun reflected from the clouds after the sun has set. There are, however, many peculiar effects at sunrise and sunset, and during the night, which will be found discussed at greater length in the author's book, *Principles of Electric Wave Telegraphy*, and also in his Cantor lectures given before the Royal Society of Arts in February, 1919, on "The Scientific Problems of Electric Wave Telegraphy." One modification of radiotelegraphy which is coming into use consists in transmitting along bare wire laid on the ground or in water or else along existing telephone or telegraph wires high frequency currents generated by the same types of generator as are used in radiotelegraphy. These oscillations can be detected and used to transmit signals by means of the valve detectors used in wireless telegraphy. This transmission can go on without interfering with the use of the circuits for ordinary telegraphy and telephony and is properly called wire-guided electric wave telegraphy, but commonly called "wired wireless."

In conclusion, we may say that radiotelegraphy has not only given to mankind a superlatively beneficial means of communication, but has also opened up for discussion physical and cosmical problems of profound interest.

The matter of greatest interest at the present time is the remarkable developments which have taken place in the thermionic valve, both as generator, detector and amplifier of electric oscillations. We are only at the very beginning of this evolution, yet it has already completely revolutionised the practical side of wireless telegraphy, as well as telephony with and without wires. The whole of our planet is now converted into one vast auditorium through which human speech can be transmitted by wireless telephony and wire telephony aided by the greatest electrical marvel of this half-century, viz., the thermionic valve and repeater which originated with the author's invention of the oscillation valve in 1904.

CONCLUSION

In bringing to a conclusion this brief and necessarily imperfect sketch of the chief achievements of applied electricity in the last half-century it may not be out of place to offer a few reflections on the manner in which these valuable gifts to humanity have been secured and on the methods by which these gains may be extended and enlarged.

It came as a shock to many in Great Britain to discover, at the outset of the Great War of 1914–18, the degree to which we had become dependent on other countries for certain manufactures involving scientific knowledge in their production.

Long years before that date the most eminent men of science had uttered serious warnings as to the consequences of Great Britain's neglect to foster pure scientific research or to organise effective methods of encouraging technical discovery and improvements. These warnings, however, fell on deaf ears. Statesmen and politicians played the party game, and complete ignorance of the simplest facts of science by members of our governing classes was considered no stigma or disqualification for holding high positions in control of departments essentially dependent on scientific knowledge for their utility. More than sixty years ago Professor Tyndall said, "I state nothing visionary when I say that in a country like ours, whose greatness depends so much upon the applications of physical science, it would be a wholesome and natural test to make admission to the House of Commons contingent on a knowledge of the principles of natural philosophy." He also added a plea for the study of physics amongst manual workers, urging it "not only as a means of mental culture, but also as a moral influence."

Experience is said to be a good schoolmaster, but he has the reputation of charging very high fees for his instruction. It is questionable whether we as a nation have yet learnt thoroughly all he has to teach on this subject of the necessity for putting in operation, without delay, carefully

thought-out plans for promoting scientific and industrial research, even in spite of the lessons given to us at great cost in the last six years. In this respect Parliament and the Press only reflect the tone of mind of the nation, and whilst a football match or elopement commands far more attention from the average person than a scientific discovery or its elucidation we can hardly hope to see much real reform.

The popular idea is that to "appoint a committee" and give them some funds to dispense is a certain remedy for prolonged neglect of any particular branch of scientific investigation. We need only look back with clear vision on the past history of scientific discovery to see this misconception in its proper light. All great and important electrical inventions have sprung out of scientific discoveries made by highly-trained and exceptionally-gifted men who had no other object at heart than the discovery of the truth and the advancement of knowledge.

Science is said to be a coy mistress who will not be wooed for the sake of her dowry of useful applications. On the other hand, the most abstract and apparently useless researches pursued in a serious and disinterested spirit have frequently formed the basis of technical inventions of unspeakable value.

If we could have peeped into the laboratories of the Royal Institution in Albemarle Street, London, in the autumn days of 1831 and seen Faraday busy with his magnets, copper wire and disks and iron bars, we might perhaps have wondered that so much time and intelligence were not better bestowed. But, as we have seen, those epoch-making experiments have rendered imperishable services to humanity. It is true great inventive power had to be bestowed to develop their full use, but the foundation was laid in the purely scientific discoveries. In the same manner Maxwell's recondite researches into the theory of electricity and Hertz's practical production of Maxwell's electromagnetic waves were the basis on which the amazing edifice of wireless telegraphy has been built up.

The investigations on electric discharge in vacuo and especially that from incandescent filaments in vacuo, which have occupied numerous workers, have led to the development of the thermionic valve, that master weapon of the radio-engineer. Dewar's researches and inventions in connection with the production of high vacua by absorption of gases by

charcoal at low temperatures, have immensely aided all other inventions depending upon such high vacua. The incandescent lamp would have been impossible without the means for making high vacua by mercury pumps which had been first developed for the purpose of studying electric discharge in vacuo. Crookes' labours in this region led Röntgen to the discovery of X-rays, and purely scientific work on the rare metals of high melting points, particularly that on tungsten, discovered in 1781 by d'Elhujar, and tantalum, first made known by Hatchett in 1802, has given us ultimately our modern metallic filament lamp. The electrothermal investigations of Moissan, an eminent French chemist, who described the production of calcium carbide by the electric arc, started the commercial extensions of his work which have become vast industries occupying tens of thousands of manual workers. If we look carefully at the history of these developments we shall see that the fundamental scientific discoveries were not made in any happy-go-lucky or casual manner. They were the result of the careful, progressive, persevering work of men unusually endowed with powers of observation, and the faculty of drawing logical inferences therefrom, and also deep knowledge of scientific history combined with a rare imaginative power which enabled them to leave beaten paths and strike out in entirely new directions.

Such minds cannot be made to order. They are not very common, and the utmost we can do for their possessors is to provide them the means of living and research and then let them alone. We can relieve them from wasting time in collecting the mere apparatus to test their ideas, or dulling their faculties of discovery by the helot work of elementary science teaching or text-book writing for a remuneration which a miner or skilled mechanic would nowadays scornfully reject.

Modern research needs in most cases expensive appliances and accommodation in which to use them. The class of investigations which can be pursued with simple apparatus are necessarily limited, and for the most part the problems pressing for solution are only possible in well-equipped institutions and often require co-operative work. Moreover, they demand continuous attention and uninterrupted thought. The conditions under which they can best be undertaken by those who have given evidence of the necessary abilities, can be provided by the more

abundant establishment of research fellowships or professorships, which free the holder of them from the necessity of giving time to distracting bread-winning labours during their tenure. We in Great Britain have a long way to go before we shall even remotely approach the provisions for the above purpose which at present exist in the United States. Some information on these provisions was given by the author in a lecture at the Royal Society of Arts on February 9th, 1916, on "The Organisation of Scientific Research" (Vol. 64, p. 245, February 11th, 1916).

In the matter of industrial and commercial research we are obliged to regard it from a different point of view. The purely scientific investigator desires to publish freely and as soon as possible the results of his investigations and make them known to all. The manufacturer or industrialist operating a business dependent on scientific knowledge or invention desires to keep his discoveries to himself or, at any rate, to maintain control over them. His great mistake in the past in Great Britain has been his want of faith in, and desire to avoid expense on, steady, persistent research carried on by highly-trained scientific men on his behalf. On the contrary, we see in the United States leading electrical corporations, such as the General Electric Company or the Western Electric Company, maintaining large staffs of the most competent and highly-trained scientific men engaged solely on the work of opening up new channels for profitable manufacture or solving technical problems and furnished with all that can possibly be required in the way of apparatus of research. The same was true of Germany before the War in even larger measure.

In Great Britain in the last three years progress has been made, under the auspices of the Committee of the Privy Council for Scientific and Industrial Research, in supporting individual and associated scientific research by grants and by assisting organised effort on the part of various trade or manufacturers' associations or technical institutions to grapple with urgent scientific problems in manufacture or production. The British Electrical and Allied Manufacturers' Association, commonly known as the B.E.A.M.A., have set aside very considerable funds for research scholarships, intended to assist the growth of technical knowledge in various departments of electrical and mechanical engineering. The

holder is required to enter into an agreement with the B.E.A.M.A. not to communicate to any unauthorised person or to publish the results of his investigation without leave and to assign to the Association all rights in any discovery he may make during his work, but the Association will reward him suitably, if the invention, design or discovery is in their opinion worthy of reward.

The Institution of Electrical Engineers has also a special research committee who are provided with the men and the means to deal with such problems as may require more than individual work or initiative to reach a solution. Whilst there is much straightforward research work of a kind which needs only well-trained workers and ample funds to carry it out we must not forget that the opening of entirely new fields of invention or discovery is always dependent on individual genius and that nothing else can supply fertile or great conceptions.

It is not an easy thing to make a truly new addition to invention or discovery or to enlarge indisputably the bounds of human knowledge. To foster such men as do possess the power we have first to create the atmosphere in which genius can live and thrive, and for this purpose there must be a widespread sympathy with and interest in scientific knowledge. Scientific teaching and the public exposition of scientific achievements are therefore important matters, and to do these things well calls for special qualities in the expositor in relation to those he has to teach.

The advanced student requires the stimulating and inspirational guidance of a great mind, such as that of a Kelvin, Maxwell or Stokes, and with such teachers it is not merely the information which they give, but the suggestions opening new lines of thought that is important.

But to set such men to teach students of only average ability is to harness Pegasus to the plough.

In ordinary class teaching the qualities most required in the teacher are lucidity of thought, novelty of treatment and, above all things, insistence upon a clear grasp of fundamental principles and avoidance of the use of words which simply conceal ignorance. Much otherwise good teaching is hindered by our absurd examination system, which often compels a teacher to cover a certain range of subjects in a limited time and, therefore, to supply new ideas or information faster than it can

effectively be assimilated by the student. Also we make success in these examinations depend too much on memory and too little on solid grasp of elementary principles. Hence, the result often is that a mere burlesque of knowledge remains in the student's mind, and is given forth in examination papers in those " howlers " which, at least, lighten the dreary work of the examiner, such as the answer of a student who, asked to define a horse-power in engineering work, promptly replied it was " the distance a horse could carry 1 lb. of water in an hour."

As regards the general public, scientific investigators owe it as a duty to the nation and to themselves to stir up and stimulate a genuine interest in the progress of our knowledge concerning the universe in which we live.

Unfortunately, those who have the greatest powers of advancing this knowledge have not always equal powers of clear, interesting and attractive explanation. These powers were combined to a remarkable degree in Faraday, Davy, Tyndall, Huxley, and many others in bygone generations, and are also in the case of many living workers. Their success was due to the fact that they made almost as great a study of the art of exposition in its manner and matter as they did of the art of discovery itself. It is, above all things, necessary that a lecturer should have an instinctive recognition of the intellectual calibre of the audience he addresses, and whilst starting from levels of thought at which they can easily follow him, lead them by degrees to greater heights and clearer views of that on which he speaks.

First, he must make himself master of the art of elocution. The speaker who turns his back on his audience and talks in a conversational tone to his blackboard or diagrams, or is too great a slave to his notes and reads every word, or whose experiments or illustrations are not a prompt success, will not inspire his audience with an enthusiasm for his subject. In addressing very popular audiences, that is, assemblies composed of persons with but little previous acquaintance with scientific ideas, one cannot be too careful to define and make clear even the simplest scientific words.

It is astonishing sometimes to discover how little meaning is conveyed to the uninstructed adult mind by words or phrases that are familiar even to the intelligent boy or girl.

On the occasion of one of the electrical exhibitions at the Crystal Palace the author was requested to give a few public lectures to make clear to visitors the mode of operation of the things on view. One of these lectures was on magnets and electric currents.

An endeavour was made to explain in simple terms the powers and properties of magnets and electric currents. The well-known experiment was shown of sprinkling a glass plate held over a magnet with iron filings to render visible the invisible curved lines of magnet force by which a magnet is surrounded. These were, as usual, projected on a screen by a powerful electric arc lantern. An old lady was asked afterwards if she liked the lecture and what it was about. "Oh, yes," she said, "it was very interesting. He told us about *maggots* (magnets!) and showed *creeping things* (shadows of iron filings) on a sheet."

But even if the result of a popular lecture is to irradiate mental obscurity with but a faint glimmer of the clear light of accurate knowledge, it is possible it may leave some hearers like Oliver Twist, "asking for more," and awaken in them the desire to satisfy the craving by serious study. In that case it will not entirely have failed in its aim.

For although the public generally regard the *applications* of scientific knowledge as of more importance than the simple pursuit of truth for its own sake, it is certain that the careful study of any branch of natural science, without regard to its utilitarian aspects, but only as an orderly presentment of the facts and laws underlying the phenomena of Nature, is an occupation which calls forth and trains the highest and noblest faculties of our minds.

APPENDIX

WORKS BY DR. J. A. FLEMING, F.R.S.

1. The Principles of Electric Wave Telegraphy and Telephony. Fourth Edition. 707 pp. £2 2*s.*

2. An Elementary Manual of Radiotelegraphy and Radiotelephony. Third Edition. 360 pp. 10*s.* 6*d.*

(Longmans, Green & Co., 39, Paternoster Row, London, E.C.)

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3. The Wireless Telegraphists' Pocket Book of Notes and Formulæ. 347 pp. 9*s.*

4. The Thermionic Valve and its Developments in Radiotelegraphy and Telephony. Part I. 279 pp. 15*s.* Part II. in the Press.

(The Wireless Press, Ltd., 12 & 13, Henrietta Street, Strand, London.)

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PUBLIC LECTURES BY DR. J. A. FLEMING, F.R.S.

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2. Electromagnetic Repulsion. March 6th, 1891.
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8. The Thermionic Valve in Wireless Telegraphy. May 21st, 1920.

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2. Waves and Ripples in Water, Air, and Æther. 1901–2.
3. Our Useful Servants, Magnetism and Electricity. 1917–18.

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1. The Induction Coil and Transformer. January 23rd, 30th, February 6th, 1892.
2. Electric Illumination. April 3rd, 10th, 17th, 24th, 1894.
3. Recent Researches in Magnetism and Diamagnetism. (Tyndall Lectures.) March 3rd, 10th, 17th, 24th, 31st, 1898.
4. Wireless Telegraphy. May 28th, June 4th, 1903.
5. Electromagnetic Waves. (Tyndall Lectures.) May 25th, June 1st, 8th, 1905.
6. Electric Heating and Pyrometry. (Tyndall Lectures.) June 4th, 11th, 1910.
7. Photo Electricity. (Tyndall Lectures.) May 1st, 8th, 1915.
8. Modern Improvements in Telegraphy and Telephony. March 22nd, 29th, 1917.

(B) Lectures at the Crystal Palace Electrical Exhibition of 1892.

Electromagnets and Electric Currents. May 11th, 18th, 25th, June 1st, 1892.

(C) Lectures at the Royal Society of Arts.

Cantor Lectures.

1. The Practical Measurement of Alternating Currents. January 30th, February 6th, 13th, 20th, 1893.

2. Alternate Current Transformers. January 20th, 27th, February 3rd, 10th, 1896.

3. Electric Oscillations and Electric Waves. November 26th, December 4th, 10th, 17th, 1900.

4. Hertzian Wave Telegraphy. March 2nd, 9th, 16th, 23rd, 1903.

5. The Measurement of High Frequency Electric Currents. November 27th, December 4th, 11th, 18th, 1905.

6. The Applications of Electric Heating. March 6th, 13th, 20th, 27th, 1911.

7. The Scientific Problems of Electric Wave Telegraphy. February 10th, 17th, 24th, 1919.

8. Elihu Thomson's Electromagnetic Induction Experiments. (Awarded a silver medal.) May 14th, 1890.

(D) Lectures before the British Association.

The Working Men's Lecture at Liverpool. The Earth a Great Magnet. September 19th, 1896.

The Evening Lecture at Dover. The Centenary of the Electric Current. September 18th, 1899.

(E) Lectures for the Gilchrist Educational Trust.

On *Magnets and Electric Currents.*

Mile End Road, Bournemouth, Dover, Faversham, Saffron Walden. 1893.
Coventry, Bedford, Redditch, Old Hill, West Bromwich, Westbourne Park. 1894.
Ashford, Watford, Ipswich, Peterborough. 1895.
Batley, Holmfirth, Leigh, Widnes, Newark. 1896.

(F) Lectures at the Royal Engineers' Institute, Chatham.

On Electric Lighting. November 25th, December 1st, 1897.
On Secondary Batteries. March 22nd, 1900.

(G) Popular Lectures at Various Institutions.

Eighty Public Lectures on Scientific Subjects between 1894 and 1904.

(H) Lectures on Educational Subjects.

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4. Engineering and Scientific Research. A Paper read to the Society of Engineers. May 1st, 1916.

5. The Organisation of Scientific Research. A Paper read to the Royal Society of Arts. February 9th, 1916.

6. The Place of Science in Education. (*Journal of the Royal Society of Arts*, June 23rd, 1916.)

PUBLISHED SCIENTIFIC PAPERS OF DR. J. A. FLEMING FROM 1874 TO 1920.

I.—On General Electrical Physics.

1. On the New Contact Theory of the Galvanic Cell. March, 1874. (*Proceedings of the Physical Society*, 1874, vol. i., p. 1.) This paper was the first paper read before the Physical Society of London at its Inaugural Meeting, in March, 1874.

2. On the Decomposition of an Electrolyte by Magneto-electric Induction. September, 1875. (*Report of the British Association*, 1875. *Electrical News*, September, 1875.)

3. On the Polarisation of Electrodes in Water free from Air. February, 1876. (*Philosophical Magazine*, February, 1876, vol. i., 5th ser., p. 142.)

4. On Magneto-electric Induction in Liquids and Production of Induced Currents in Electrolytes. 1877. (*Proceedings of the Royal Society*, 1877, vol. xxvi., p. 40.)

5. Problems on the Distribution of Electric Currents in Networks of Conductors treated by the Method of Maxwell. June, 1885. (*Proceedings of the Physical Society*, 1885, vol. vii., p. 215.)

6. On Electric Discharge between Electrodes at different Temperatures in Air and in High Vacua. December, 1889. (*Proceedings of the Royal Society*, 1889, vol. xlvii., p. 118.)

7. On the Electrolysis of Gas and Water Pipes by the Current from Electric Tramways. (*Proceedings of the British Association*, Bristol, 1898.)

8. A Note on the Photo-electric Properties of Potassium-Sodium Alloy. (*Philosophical Magazine*, February, 1909. *Proceedings of the Physical Society*, vol. xxi., p. 469.)

9. The Centenary of the Electric Current. An Evening Discourse delivered before the British Association at Dover, 1899.

10. The Electronic Theory of Electricity. A Friday Evening Discourse delivered at the Royal Institution.

11. On a Model illustrating the Propagation of a Periodic Electric Current in a Telephone Cable. (*Philosophical Magazine*, June, 1904. *Proceedings of the Physical Society*, 1905, vol. xix., p. 310.)

12. An Experimental Method for the Production of Vibrations on Strings illustrating the Properties of Loaded and Unloaded Telephone Cables. (*Proceedings of the Physical Society*, London, December 15th, 1913, vol. xxvi, p. 61.)

13. An Instrument for the Optical Delineation and Projection of Physical Curves. (*Proceedings of the Physical Society*, London, June, 1915, vol. xxvii., p. 316.)

14. The Effect of Electrical Oscillations on the Magnetic Properties of Iron investigated by the Campograph. (*Proceedings of the Physical Society*, London, December, 1915, vol. xxviii., p. 35.)

15. A Note on the Derivation of the General Equation for Wave Motion in an Electric Medium. (*Proceedings of the Physical Society*, London, April 15th, 1917, vol. xxix., p. 185.)

II.—On Electrical Measurements and Measuring Instruments.

1. On a new Form of Resistance Balance adopted for comparing Standard Coils. February, 1880. (*Proceedings of the Physical Society*, 1880, vol. iii., p. 174.)

2. On the Use of Daniell's Cell as a Standard of Electromotive Force. August, 1885. (*Proceedings of the Physical Society*, 1885, vol. vii., p. 161.)

3. A Design for a Standard of Electrical Resistance. January, 1889. (*Proceedings of the Physical Society*, 1889, vol. x., p. 12.)

4. On the Necessity for a National Standardising Laboratory for Electrical Instruments. 1885. (*Proceedings of the Society of Telegraph Engineers and Electricians*, 1885, vol. xiv., p. 488.) The Paper on the National Standardising Laboratory for Electrical Instruments is acknowledged to have originated the movement which resulted in the establishment of the Board of Trade Electrical Laboratory. This Paper was written and published some considerable time prior to the establishment of the German Physikalisch-Technische Reichsanstalt or the French Laboratoire de l'Electricité.

5. Our Electric Units. (*The Electrician*, December, 1899, vol. 44, pp. 328, 366, 402.)

6. A Note on the Electrical Resistivity of Electrolytic Nickel. (*Proceedings of the Royal Society*, 1899, vol. 66, p. 50.)

7. On a Model which Imitates the Behaviour of Dielectrics. (With Mr. Ashton.) (*Philosophical Magazine*, August, 1901. *Proceedings of the Physical Society*, 1901, vol. xvii., p. 745.)

8. On the Measurement of Small Capacities and Inductances. (With Professor Clinton.) (*Philosophical Magazine*, May, 1903. *Proceedings of the Physical Society*, 1903, vol. xviii., p. 190.)

9. On a Hot Wire Ammeter for the Measurement of Small Alternating Currents. (*Philosophical Magazine*, May, 1904. *Proceedings of the Physical Society*, 1905, vol. xix., p. 173.)

10. A Note on the Measurement of Small Inductances and Capacities. (*Philosophical Magazine*, May, 1904. *Proceedings of the Physical Society*, 1905, vol. xix., p. 160.)

11. The Predetermination of the Current and Voltage at the Receiving End of a Telephone Line. (*Journal of the Institution of Electrical Engineers*, May, 1914, vol. lii., p. 717.)

III.—On Arc and Incandescence Electric Lamps.

1. On the Phenomena of Molecular Radiation in Incandescence Lamps. (*Proceedings of the Physical Society*, 1883, vol. v., p. 283.)

2. On Molecular Shadows in Incandescence Lamps. 1885. (*Proceedings of the Physical Society*, 1885, vol. vii., p. 178.)

3. On the Characteristic Curves and Surfaces of Incandescence Lamps. 1885. (*Proceedings of the Physical Society*, 1885, vol. vii., p. 55.)

4. On Electric Lighting in Works and Factories. 1887. (*Journal of the Iron and Steel Institute*, No. II., 1887.)

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6. An Analytical Study of the Alternating Current Arc. 1896. (*Proceedings of the Physical Society*, 1896, vol. xiv., p. 115.)

7. A Further Examination of the Edison Effect in Glow Lamps. 1896. (*Proceedings of the Physical Society*, 1896, vol. xiv., p. 187.)

8. The Photometry of Electric Lamps. (*Journal of the Institution of Electrical Engineers*, 1903, vol. xxxii.) This Paper gained the Institution Premium.

9. On Large Bulb Incandescent Electric Lamps as Secondary Standards of Light. (*Proceedings of the British Association*, Cambridge, 1904. *Electrical Engineer*, August 26th, 1904.)

10. On the Ratio between Mean Spherical Candle-power and Mean Horizontal Candle-power of Incandescence Lamps. (*Philosophical Magazine*, August, 1905. *Proceedings of the Physical Society*, 1905, vol. xix., p. 681.)

IV.—On Alternating Currents and Transformers.

1. Some Effects of Alternating Current Flow in Circuits having Capacity and Self-induction. 1891. (*Journal of the Institution of Electrical Engineers*, 1891, vol. xx., p. 362.)

2. Experimental Researches on Alternate Current Transformers. 1892. (*Journal of the Institution of Electrical Engineers*, 1892, vol. xxi., p. 594.) This Paper was a record of an exhaustive series of tests on transformers, and it settled the question of open *versus* magnetic circuits. It has been freely quoted as authoritative in every text-book since.

3. A Reply to a Discussion of a Paper on Alternate Current Transformers. 1893. (*Journal of the Institution of Electrical Engineers*, 1893, vol. xxii., p. 77.)

4. On Elihu Thomson's Electromagnetic Induction Experiments. 1890. (*Journal of the Society of Arts*, May, 1890.)

5. On Electromagnetic Repulsion. Friday Evening Discourse. 1891. (*Proceedings of the Royal Institution*, 1891, vol. xiii., p. 296.)

6. On the Power Factor and Conductivity of Dielectrics when Tested with Alternating Currents of Telephonic Frequency at various Temperatures. (With Mr. Dyke.) (*Journal of the Institution of Electrical Engineers*, 1912, vol. xlix.) Awarded the Institution Premium.

V.—On Magnetism.

1. A Method of Determining Magnetic Hysteresis Loss in Straight Iron Strips. 1897. (*Proceedings of the Physical Society*, 1897, vol. xv., p. 202.)

2. The Earth, a Great Magnet. British Association Lecture. September, 1896. (*Terrestrial Magnetism*, 1896, vol. ii., p. 45.)

3. The Ferromagnetic Properties of Iron and Steel. (*Proceedings of the Sheffield Society of Engineers and Metallurgists*, 1897.)

4. On the Magnetic Hysteresis of Cobalt. (*Proceedings of the Physical Society*, 1899, vol. xvi., p. 519.)

5. On the Magnetic Qualities of some Alloys not containing Iron. (With Sir Robert Hadfield.) (*Proceedings of the Royal Society*, 1905, vol. 76A, p. 271.)

VI.—On Electric Oscillations and Electric Wave Telegraphy.

1. The Propagation of Electric Waves along Spiral Wires and on an Appliance for Measuring the Length of Waves used in Wireless Telegraphy. (*Philosophical Magazine*, October, 1904.) This was a Paper read to the British Association at Cambridge.

2. The Present State of Wireless Telegraphy. Electrical Congress of St. Louis. 1904.

3. An Instrument for the Measurement of the Length of long Electric Waves and also small Inductances and Capacities. (*Proceedings of the Royal Society*, 1905, vol. 74, p. 488.)

4. On the Conversion of Electric Oscillations into Continuous Currents by Means of a Vacuum Valve. (*Proceedings of the Royal Society*, 1905, vol. 74, p. 476.) This Paper described the first thermionic detector or oscillation valve in wireless telegraphy.

5. The Application of the Cymometer to the Measurement of small Capacities, Inductances and Co-efficients of Coupling of Oscillation Transformers as used in Wireless Telegraphy. (*Philosophical Magazine*, June, 1905. *Proceedings of the Physical Society*, 1905, vol. xix., p. 603.)

6. On the Theory of Directive Antennæ or Unsymmetrical Hertzian Oscillators. (*Proceedings of the Royal Society*, 1906, vol. 78A, p. 1.)

7. The Construction and Use of Oscillation Valves for Rectifying High-frequency Electric Oscillations. (*Philosophical Magazine*, May, 1906. *Proceedings of the Physical Society*, 1906, vol. xx., p. 177.)

8. Some Observations on the Poulsen Arc as a Means of obtaining Continuous Electrical Oscillations. (*Philosophical Magazine*, August, 1907. *Proceedings of the Physical Society*, 1908, vol. xxi., p. 23.)

9. On the Electric Radiation from Bent Antennæ. (*Proceedings of the Physical Society*, 1907, vol. xx., p. 409.)

10. On Magnetic Oscillators as Radiators in Wireless Telegraphy. (*Philosophical Magazine*, December, 1907. *Proceedings of the Physical Society*, 1908, vol. xxi., p. 47.)

11. Recent Contributions to Electric Wave Telegraphy. A Friday Evening Discourse at the Royal Institution. May 24th, 1907. Lord Kelvin in the chair.

12. Researches in Radiotelegraphy. A Friday Evening Discourse at the Royal Institution. June 4th, 1909.

13. Some Quantitative Measurements in connection with Radiotelegraphy. (*Journal of the Institution of Electrical Engineers*, 1910, vol. xliv.)

14. The Function of the Earth in Radiotelegraphy. (*Engineering*, June 4th, 11th, 1909.)

15. A Note on the Production of Steady Electric Oscillations in Closed Circuits and a Method of Testing Radiotelegraphic Receivers. (*Philosophical Magazine*, May, 1909. *Proceedings of the Physical Society*, 1909, vol. xxi., p. 657.)

16. The Effect of an Air-blast upon the Spark Discharge of a Condenser charged by an Induction Coil or Transformer. (*Philosophical Magazine*, May, 1909. *Proceedings of the Physical Society*, 1909, vol. xxi., p. 665.)

17. The Measurement of the Energy Loss in Condensers traversed by High-frequency Electric Oscillations. (With Mr. Dyke.) (*Proceedings of the Physical Society*, 1911, vol. xxiii., p. 117.)

18. Some Resonance Curves taken with Impact and Spark Ball Dischargers. (With Mr. Dyke.) (*Proceedings of the Physical Society*, 1911, vol. xxiii., p. 136.)

19. A Note on the Experimental Measurement of the High-frequency Resistance of Wires. (*Proceedings of the Physical Society*, 1911, vol. xxiii., p. 103.)

20. Some Oscillograms of Condenser Discharges and a Simple Theory of Coupled Circuits. (*Proceedings of the Physical Society*, 1913, vol. xxv., p. 217.)

21. On Atmospheric Refraction and its Bearing on the Transmission of Electromagnetic Waves round the Earth's Surface. (*Proceedings of the Physical Society*, 1914, vol. xxvi., p. 318.)

22. A Four-electrode Thermionic Detector for Damped and Undamped Electric Oscillations of High or Low Frequency. (*The Wireless World*, 1920, vol. viii., December 25th, p. 676.)

PAPERS PUBLISHED CONJOINTLY WITH SIR JAMES DEWAR, F.R.S.

VII.—On Electric and Magnetic Properties of Matter at Low Temperatures.

1. On the Electrical Resistance of Pure Metals, Alloys and Non-Metals at the Boiling Point of Oxygen. (*Philosophical Magazine*, October, 1892, p. 326.)

2. On the Electrical Resistance of Metals and Alloys at Temperatures approaching the Absolute Zero. (*Philosophical Magazine*, September, 1893, p. 271.)

3. Thermoelectric Powers of Metals and Alloys between the Temperature of the Boiling Point of Water and the Boiling Point of Liquid Air. (*Philosophical Magazine*, July, 1895, p. 95.)

4. The Variation in the Electrical Resistance of Bismuth when cooled to the Temperature of Solid Air. (*Philosophical Magazine*, September, 1895, p. 303.)

5. On the Changes produced in Magnetised Iron and Steel by cooling to the Temperature of Liquid Air. (*Proceedings of the Royal Society*, 1896, vol. 60, p. 57.)

6. On the Electrical Resistivity of Bismuth at the Temperature of Liquid Air. 1896. (*Proceedings of the Royal Society*, vol. 60, p. 72.)

7. On the Magnetic Permeability and Hysteresis of Iron at Low Temperatures. 1896. (*Proceedings of the Royal Society*, vol. 60, p. 81.)

8. On the Electrical Resistivity of Pure Mercury at the Temperature of Liquid Air. 1896. (*Proceedings of the Royal Society*, vol. 60, p. 76.)

9. On the Magnetic Permeability of Liquid Oxygen and Liquid Air. 1896. (*Proceedings of the Royal Society*, vol. 60, p. 283.)

10. On the Dielectric Constant of Liquid Oxygen and Liquid Air. (*Proceedings of the Royal Society*, vol. 60, p. 358.)

11. On Electric and Magnetic Research at Low Temperatures. Friday Evening Discourse. June 5th. (*Proceedings of the Royal Institution*, 1896, vol. 15, p. 239.)

12. On the Electrical Resistivity of Electrolytic Bismuth at Low Temperature and in Magnetic Fields. 1897. (*Proceedings of the Royal Society*, vol. 60, p. 425.)

13. Note on the Dielectric Constant of Ice and Alcohol at Very Low Temperatures. 1897. (*Proceedings of the Royal Society*, vol. 61, p. 2.)

14. On the Dielectric Constants of Pure Ice, Glycerine, Nitro-benzol and Ethylene Dibromide, at and above the Temperature of Liquid Air. 1897. (*Proceedings of the Royal Society*, vol. 61, p. 316.)

15. On the Dielectric Constants of certain Frozen Electrolytes at and above the Temperature of Liquid Air. 1897. (*Proceedings of the Royal Society*, vol. 61, p. 299.)

16. Further Observations on the Dielectric Constants of Frozen Electrolytes at and above the Temperature of Liquid Air. 1897. (*Proceedings of the Royal Society*, vol. 61, p. 381.)

17. On the Dielectric Constants of certain Organic Bodies at and above the Temperature of Liquid Air. 1897. (*Proceedings of the Royal Society*, vol. 61, p. 358.)

18. On the Dielectric Constants of Metallic Oxides dissolved or suspended in Ice cooled to the Temperature of Liquid Air. 1897. (*Proceedings of the Royal Society*, vol. 61, p. 368.)

19. A Note on some further Determination of the Dielectric Constants of Organic Bodies and Electrolytes at Very Low Temperatures. 1897. (*Proceedings of the Royal Society*, vol. 62, p. 250.)

20. On the Magnetic Susceptibility of Liquid Oxygen. 1898. (*Proceedings of the Royal Society*, vol. 63, p. 311.)

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